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AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

ART. XI.—*An Investigation into the Elastic Constants of Rocks, more especially with reference to Cubic Compressibility;* by FRANK D. ADAMS and ERNEST G. COKER.

Introduction.—In a paper published in 1901 an account was given of an investigation into the deformation of marble under varying conditions of heat and pressure.* Under a grant from the Carnegie Institution of Washington to F. D. Adams, the experimental investigation into the behavior of rocks under pressure has been continued in the laboratories of McGill University. As the investigation went forward, however, it was found necessary to follow out several separate lines of research, the results of which it is proposed to present in a series of separate papers.

In the present article a brief résumé is presented of the methods adopted and the results obtained in an investigation into the elastic constants of rocks, more especially with a view to ascertaining the amount of cubic compression which rocks will undergo when submitted to pressure from every side, all rocks of course being subjected to such compression to a greater or less extent, previous to the deformation which they suffer under conditions of differential pressure.

A full presentation of the results of the investigation will be found in a Publication of the Carnegie Institution of Washington, No. 46, having the same title as the present paper, and which is now in press, to which the reader is referred for full details of all the measurements carried out in the case of each of the specimens examined, as well as for detailed descriptions,

* Adams, F. D., and Nicolson, J. T. An experimental investigation into the Flow of Marble. Phil. Trans. Royal Soc. London, Series A, vol. cxcv, pp. 363–401.

color process photographs and microphotographs of each of the rocks employed. Before the investigation was completed, Dr. Coker was called to the Professorship of Mechanical Engineering in the Finsbury Technical Institute of London, England, and was accordingly obliged to give up the work of the research. His place was taken by Mr. Charles McKergow, Lecturer in Mechanical Engineering in McGill University, but who, immediately on the completion of the work, was appointed to the Professorship of Mechanical Engineering in the University of Virginia. A large number of the very careful measurements of the elastic constants which are presented in the paper were made by Professor McKergow.

Methods which may be used in the determination of the Elastic Constants of Materials.

The determination of the cubic compressibility of solid substances is, as above mentioned, beset with serious difficulties. On one hand every direct method which has been suggested presents experimental difficulties which tend to impair its accuracy, while on the other hand the indirect methods are based on assumptions as to the isotropy of the materials, which are not warranted in the case of certain rocks. The indirect methods, however, depending on the theory of elasticity, are capable of considerable variation, and it is of interest to examine them in some detail in order to see whether certain of them at least may not be depended upon to give reliable and satisfactory results.

The determination of the elastic constants of metals has engaged the attention of many physicists and at the present time a large amount of information exists as to the values of these constants for various metals.

It is well known that in homogeneous elastic substances, a simple compression stress causes a lateral strain, which bears a fixed ratio to the compression strain for any particular substance within the limit of elasticity. If then* we call p_x the stress on a plane perpendicular to x in the direction x, and e_x the corresponding strain, then for a direct compression stress p_x there will be a strain in the direction of this stress of amount p_x/E, where E is Young's modulus, and lateral strain of magnitude p_x/mE, where m is the ratio of the longitudinal compression to the lateral extension per unit of length.

If we suppose further that a body is subjected to cubical stress of intensity p_x, we easily see that for small and therefore superposable strains, the cubical strain e_c is

$$e_c = 3p_x \frac{m-2}{mE}$$

*See Ewing's Strength of Materials, Chapters I and II.

and since the modulus of compressibility D is the ratio of the stress per unit of area to the cubical strain produced, we have

$$D = \frac{p_x}{e_c} = \frac{1}{3}\,\frac{m}{m-2}\,E$$

Hence if we know E and m we can calculate the value of D.

Further, it is shown in treatises on elasticity that if C is the modulus of shear, then

$$C = \frac{1}{2}\,\frac{m}{m+1}\,E$$

and since C and E are quantities which can be ascertained by experiment, we can from them calculate m and D.

In an important paper by Nagaoka* this latter method has been used to determine the elastic constants of a series of rocks. The value of E was determined by supporting a bar at the ends and measuring the angular change at the support due to a given load applied at the center; the value of E is then obtained by the formula $E=3wl^2/4bd^3\theta$, where l is the length of the bar between the supports, b is the breadth of the bar, d the depth and θ the angular change at the ends for a load W. In order to determine the value of m, a specimen of rectangular section was twisted by a given torque, T, and the amount of the strain measured. It has been shown by St. Venant that for such a case the value of C is given by the formula

$$T = C\theta b^3 h \left[\frac{16}{3} - \frac{32^2 b^4}{\pi^5} \sum_0^\infty \frac{\tan h\,(2n+1)\,\frac{\pi h}{2b}}{(2n+1)^5}\right]$$

where θ is the angular change, and from this formula values of C were calculated from the observations.

This method appears to be open to some minor objections in that the formula for determining E is based upon a theory of flexure, which although sufficient for many purposes is nevertheless only approximate, and it is well known that values of E obtained by flexure experiments in this manner often differ from the values of E obtained by direct compression experiments by not inconsiderable amounts.

Further, in experiments upon the deflection of beams cut from rocks, it is difficult to obtain consistent readings because of the time effect of the loading, and this difficulty is noticed in the paper cited.

Experiments on the determination of the elastic constants of rocks when subjected to twist were also found to be fre-

* Elastic Constants of Rocks and the Velocity of Seismic Waves; H. Nagaoka.—Phil. Mag., vol. L, 1900, p. 53.

quently unsatisfactory owing to the low ultimate shearing value of many rocks.

While a glance at the list of rocks whose elastic constants have been measured by Nagaoka will at once show that most of them are rocks whose elasticity must be of a very imperfect kind, e. g., weathered clay slate, schalstein, tuff, etc.; the method which he has employed for the determination of Young's modulus gives very low results, even in the case of rocks such as marble and granite, where the elasticity might be supposed to be of a high order and comparable to that which these rocks are shown to possess in the case of the types selected for investigation in the present paper. This is seen in the following figures representing the values obtained by him for each of the marbles and granites contained in his list:

Paleozoic Marble:	E (Young's modulus).
No. 11A	10,120,000
11B	7,950,000
12A	5,440,000
12B	4,770,000
Granite	
No. 69 (Shodoshima)	6,140,000
68 (Hitachi)	2,853,000
71 (")	2,175,000
56 (")	1,588,000
52 (")	3,265,000

Of these, marble No. 11, if a mean of the two readings be taken, has about the same modulus as the average of those on our list, while No. 12 is very much lower. The highest value given for any granite in Nagaoka's list, viz: No. 69, is somewhat higher than that of the lowest of the granites in our series, that from Stanstead. The other granites examined by Nagaoka have values for E assigned to them which are so low that they are comparable only to that of the sandstone in our series. Of the three sandstones included in Nagaoka's list the Izumi sandstone of the Mesozoic has modulus of 1,322,000, while the other two, which belong to the Diluvium, have values for E of 587,500 and 583,000 respectively.

And so when an attempt is made to calculate the cubic compression (D) from the values given in Nagaoka's list and obtained by his method, it is found that a negative value is actually obtained in about one-third of the rocks which he has examined. His figures, however, were intended chiefly for the purpose of calculating the velocity of the propagation of earthquake shocks.

In consequence of a number of somewhat unsatisfactory results obtained by the writers in some preliminary experiments

with this method, as well as the facts with regard to Nagaoka's figures just mentioned, it was decided to adopt a somwhat different method and one which avoided both torsion and flexure and depended simply on strain produced by simple compressive stress. This will be termed the "Method of Simple Compression." Among the possible indirect methods, this seems to be the most satisfactory, since the assumptions necessary in the calculation of compressibility are reduced to a minimum, and the range of stress for which the ratio of stress to strain is practically constant is great.

It was found possible to measure the strain obtained very accurately by means of an apparatus forming part of the equipment of the testing laboratory of McGill University, for the

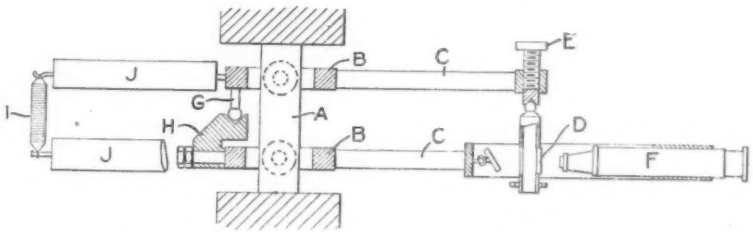

FIG. 1. Instrument for determining the modulus of a simple strain.

use of which we are indebted to Professor H. T. Bovey. This is an instrument designed by Professor Ewing, and of which a sketch is given in figure 1. In this, *A* is a specimen of the rock gripped by screws passing through a pair of collars, *B*, which are 1·25 inch apart, to which latter metal rods, *C*, are attached. The upper rod carries a glass plate, *D*, with a fine line scratched upon it, the position of which can be adjusted by a screw, *E*, while the lower rod carried a micrometer-microscope, *F*. The upper and lower collars, *B*, are connected by a stud, *G*, the upper one engaging with the conical hole of the swivel piece, *H*, in the lower, and contact is maintained by a spring, *I*, while the weights of the microscope and projecting arms are balanced by lead cylinders, *J*. A buzzer was attached to the upper lead cylinder which when operated caused a slight vibration in the instrument, producing a perfect adjustment as the pressure was applied.

The proportions of this instrument were so adjusted that one division on the micrometer scale corresponded to $\frac{1}{2500000}$ of an inch, and before using it the instrument was calibrated by aid of a Whitworth measuring machine and was found to be in correct adjustment.

The linear strain perpendicular to the length of the specimen was measured by an instrument which had been designed by E. G. Coker some time previously for experiments on the lateral strains developed in metals.* This is shown in figure 2, and consists of a pair of brass tubes, B, B', provided with set screws, A, A', for attachment to the specimen, and connected together by a flexible steel plate, F, forming the ful-

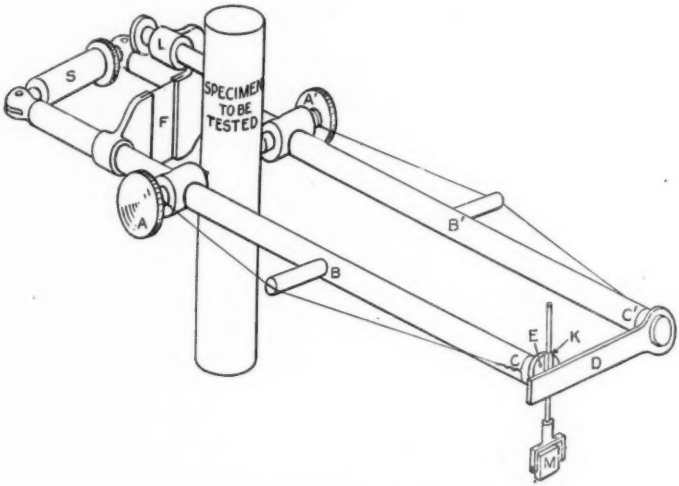

FIG. 2. Perspective view of lateral extensometer.

crum. The ends of the tubes near the fulcrum plate are pressed apart by an adjustable spring, S, to insure a uniform pressure on the screw points gripping the specimen. On the opposite end of one of the tubes is a spring, D, of ebony pressing against a double knife-edge, K, seated in a shallow V-notch cut in the end of the other arm. The knife-edge carries an adjustable mirror, M, so that if any change in the diameter of the specimen occurs the two tubes move relatively to one another in a horizontal plane, thereby causing the knife-edge mirror to rotate; the rotation of this latter is observed and measured by a telescope and scale placed at a suitable distance.

For convenience in adjustment, there is a screw, L, for tilting the apparatus about the axis of the gripping screws, and the tubes, B, B', are trussed to prevent vibration. This instrument was calibrated by aid of a Whitworth measuring

*See Proceedings Royal Soc. Edinburgh, Session 1904-5, vol. xxv, pt. vi.

machine and the scale adjusted so that one division corresponded to one millionth of an inch.

Application of the Method of Simple Compression to the Determination of the Cubic Compressibility of Metals.

The behavior of such metals as wrought iron and steel over a wide range of stress shows that these metals may be considered as almost perfectly elastic. The results of the theory of elastic bodies may therefore be applied in their cases with great confidence.

As a typical example of the behavior of such materials we may consider the deportment of a specimen of wrought iron when subjected to a cycle of compression stresses, commencing at 1,000 pounds and rising to 9,000 pounds, afterwards returning to the original load. The readings obtained for the longitudinal and lateral strains will show in such a case that equal increments or decrements of load produce strains which are very exactly proportional thereto. This is clearly shown in a plot of these readings, where the ordinates represent the total load and the abscissæ represent strains. In both cases the relation of stress to strain is represented by a straight line returning upon itself. Traces which vary but very little from the ideal straight line are given by black Belgian marble, as will be seen on page 114.

Such results afford an arbitrary standard by which can be judged the degree of approximation to perfect elasticity exhibited by other metals and by rocks under similar conditions.

If we now calculate the value of the modulus E for simple compression, since this is the relation of the compression stress p to the strain e, we have

$$p = Ee.$$

If we call A the cross-sectional area of the specimen when stressed by a load P, and x the decrease of length over a measured length L, gripped between the screw points of the measuring apparatus, we obtain

$$E = \frac{PL}{xA}$$

which in the case of a specimen of wrought iron examined for a range of 8,000 pounds, gave a value of 28,100,000, the units being pounds and inches.

The ratio m of the longitudinal strain to the lateral strain in the same case was 3·65, and using the formula

$$D = \frac{1}{3}\,\frac{m}{m-2}\,E$$

we obtain for the modulus of cubical compression (or bulk modulus) D, the value 21,300,000, a constant for the material, the reciprocal of which gives the decrease in volume of 1 cubic inch for 1 pound of pressure.

While certain rocks, such as many of the marbles, have a structure identical with that of wrought iron, most of the rocks constituting the earth's crust are composed of several minerals, and thus rather resemble cast iron in character, the gray variety of this substance being an aggregate of crystals or individuals of the metal iron (wrought iron), graphite, etc.

It will therefore be of interest to ascertain how a specimen of cast iron behaves under compression stress, and how far its elasticity falls short of that which would be exhibited by a perfectly elastic body.

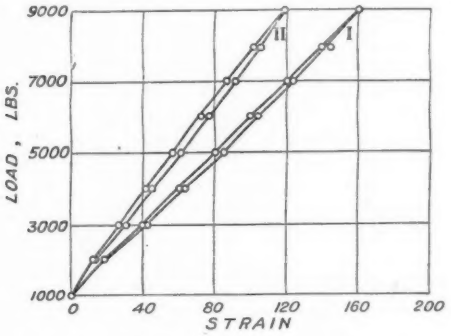

FIG. 3. Cast iron stress strain curves.

For this purpose a fine-grained specimen of somewhat hard cast iron was faced and tested. The stress strain curves are plotted in figure 3. I represents longitudinal compression and II lateral extension.

The behavior of cast iron as exhibited by these experimental results shows a falling away from the theoretical standard of perfect elasticity, but even in the most perfectly elastic bodies there is probably a slight hysteresis effect, so that we are justified in using the results obtained to calculate the modulus of compressibility, if the error introduced thereby is negligible or very small.

It may be pointed out that this method and others of the indirect type have been freely used to obtain values of the bulk modulus for cast iron and metals of like character, and it will be shown that the composite crystalline rocks are very similar to cast iron in their behavior under stress, although generally more perfectly elastic.

Application of the Method of Simple Compression to the Determination of the Compressibility of Rocks.

As has been noted, it was found in the case of marble when subjected to bending stress, that the strain as exhibited by the deflection of a point of the bar increases with the time, and the strength under shear produced by a torque was also so small that a determination of the strain was very difficult to measure.

These difficulties have been noted by Nagaoka,* who states that "Preliminary experiments on granite showed that Hooke's law does not hold even for very small flexure and torsion, and that the after effect is very considerable when the prism is sufficiently loaded or twisted; the deviation from the direct proportionality between strain and stress was incomparably great as compared with that observed in common metals. This must be chiefly due to the low limit of elasticity, so that it is necessary to experiment only within narrow limits of loading and twisting. These limits are widely different for different specimens of rocks, and the modulus of elasticity as well as that of rigidity was always determined with such stresses as will approximately produce strains proportional to them. The deviation from Hooke's law was prominent in certain specimens of sandstone, and it was more marked in torsion than in flexure experiments; in certain rocks it is indeed doubtful if anything like a proportionality between stress and strain can be found, even for extremely small change of shape: on releasing these rocks from stress the return toward the former state is extremely small, showing that the elasticity of the rocks is of very inferior order."

If, however, the rock be subjected to direct compression, strains in which the time effect is small, and the lag of the strain is also small, are almost invariably obtained. This is especially the case if, before the actual experiment is carried out, the material be several times subjected to a range of stresses at least as great as those employed in the experiment itself. This preliminary stressing brings the material to a "state of ease," and is also commonly adopted when the elastic constants of metals are determined.

It is evident therefore that this Direct Compression Method may with confidence be applied to the measurement of the cubic compression of rocks, although as mentioned below the accuracy of the results obtained will differ with different classes of rocks. If the rocks be massive, compact and crystalline (or glassy), the method can be safely employed and good results will be obtained. If, on the other hand, the rock is

* Elastic Constants of Rocks and the Velocity of Seismic Waves; Nagaoka, H.—Phil. Mag., vol. L, 1900, p. 58.

schistose, porous or loosely coherent, the method will, from the nature of the case, be very much less satisfactory.

The plutonic igneous rocks as a class most nearly resemble the metals in structure, being holocrystalline and massive, and therefore present the nearest approach among rocks to perfectly elastic bodies: they are therefore a class of rocks to which this method is especially applicable. It fortunately happens that they also form a class of rocks a knowledge of whose compressibility is of special importance for the elucidation of geological problems, constituting as they do the greater part of the earth's crust.

A second class of rocks which are comparable to them in their approach to perfect elasticity, comprises the marbles and certain limestones.

A series of sixteen typical rocks representative of these two classes were accordingly selected for measurement; under the first class a number of granites were chosen as representing the acid plutonic rocks, and a number of types of the gabbro-essexite series were selected as representing the basic plutonic rocks. In all cases great care was taken to choose the most homogeneous and massive rocks of each series, and to secure test pieces free from all flaws and cracks. As representing the second class a number of typical marbles and limestones, also perfectly massive in character, were selected. For purposes of comparison, or contrast, a sandstone was added to the list as being a rock which, on account of its more or less porous nature, could hardly be expected to yield satisfactory results by this method.

An examination of the stress strain curves of these 16 rocks, omitting the sandstone, shows that on the average they possess a rather more perfect elasticity and exhibit less hysteresis than cast iron. Some of them, as for instance, the Baveno granite, the nepheline syenite, the diabase and the black Belgian marble, show much better curves, approximating in fact to the straight lines given by wrought iron, which may be considered for our present purpose as expressing perfect elasticity.

The close approximation to perfect elasticity is shown by the return of the curve to its initial or starting point, and the amount of the hysteresis is shown by the width of the loop.

The width of this hysteresis (or lag) curve or loop indicates the amount of the divergence from Hooke's law which the material exhibits—this law being that the stress and strain are *directly* proportional. When the curve is narrow, as it is in all cases except the Stanstead granite and the sandstone, the divergence from Hooke's law is not great enough to seriously affect the result.

The rocks, therefore, with these exceptions, fulfil the conditions of elasticity necessary to the successful application of the

method. In these two cases the results are less certain owing to the greater hysteresis of the rock.

It might at first sight appear that while the method employed is theoretically perfect as applied to the measurement of the compressibility of vitreous rocks and of very fine-grained crystalline rocks, a considerable error might be introduced when the rocks are coarser in grain. In the case of all the common crystalline rocks, the individual grains of which the rock is composed are anisotropic, that is they have different moduli of elasticity in different directions. In massive rocks such as those investigated, however, these grains occur in the rock with an absolutely irregular orientation and would in the case of a fine-grained rock mutually compensate for one another in any transverse line along which the expansion of the rock under compression might be measured. If, however, the rock were coarser in grain, fewer individual crystals would be found in any transverse line of section, and there might possibly in this way be lack of compensation, as the rock in one section might be composed of grains whose axis of greater elasticity approximated on an average more nearly to the direction of measurement than in other sections. If such were really the case, there should be in these coarser-grained rocks an exceptionally great variation in the readings obtained from different specimens of the same rock, as well as from the different sections in the same specimen.

But such is not the case, as will be seen by an examination of the figures in the accompanying table. These represent the results obtained from ten measurements of the compressibility of Baveno granite, which is coarse in grain, and ten of Sudbury diabase, which is very fine in grain, together with eight measurements of Tennessee limestone, which is rather coarse grain, and seven of plate glass. They were made in each case on two or more specimens cut from the same mass, and the measurements of the expansion were made on several different planes through each, so that in every case the measurement was effected in a different line through the rock, all of these, however, of course being at right angles to the direction of the compressive stress and lying in the medial plane of the column.

	Maximum.	Minimum.	Difference.
Baveno granite (coarse), 10 trials	4,880,000	4,380,000	500,000
Sudbury diabase (very fine), 10 trials	11,170,000	9,655,000	1,515,000
Plate glass, 13 trials	6,930,000	6,020,000	910,000
Tennessee marble (rather coarse), 7 trials	6,130,000	5,770,000	360,000

It will thus be seen that there is no correspondence between the coarseness of grain and the magnitude of the variations in the readings obtained. The differences in glass, which is an

isotropic material in which the elasticity is equal in all directions, are greater than in the Tennessee marble, which is rather coarse in grain, and in Baveno granite, which is the coarsest rock of the set. The greatest differences obtained are those found in the finest-grained rock in the series, viz., the Sudbury diabase.

It is evident therefore that the different moduli of elasticity of the constituent grains of a rock do not introduce any perceptible error in measurements made by this method, when a column an inch in diameter is employed, and when the rocks are not coarser in grain than the Baveno granite. In fact, when surrounded on all sides by other grains, no individual grain can expand freely, as it would if subjected to compression unhampered by any surrounding medium, and thus the anisotropic character of the individual grains produces but little effect on the elasticity of the rock as a whole.

These experiments also show that in the case of rocks composed of several minerals, it makes no perceptible difference whether the points of attachment of the instrument are embedded in the grains of one mineral or of another. The chief source of error, and the one to which the variations observed are for the most part to be attributed, seems to be a mechanical one, viz., the difficulty of getting an ideal contact between these points of attachment and the specimen, especially in view of the extremely small dimensions of the movement to be measured.

The question of the influence of temperature on the elasticity and compressibility of rocks is of course one which has an important bearing on certain problems of geophysics. The only investigation of this subject, so far as can be ascertained, consists of a few preliminary experiments by Nagaoka and Kusakabe.* In these the torsion method was employed, and the experiments were carried out on a single rock, viz., sandstone. This rock, as has already been mentioned, being porous and stratified in character, is a material whose elastic properties are far from ideal. The results are summed up by the authors in the following words: "Preliminary experiments with sandstone show that the modulus of elasticity is much affected by the variation of temperature, i. e., about 0·5 per cent. per degree. It does not, however, necessarily diminish with the increase of temperature where the temperature is low, i. e., it is maximum about 9° C."

As has been shown, however, the values for the elastic constants obtained by this torsion and bending method have yielded results which cannot in all cases be correct, and which differ very considerably from those obtained by the much more

* Modulus of Elasticity of Rocks, and Velocities of Seismic Waves, Publications of the Earthquake Investigation Committee, No. 17, Tokyo, 1904, p. 43.

direct and simple method which has been employed in the present paper. These results bearing on the variation of elasticity induced by changes of temperature, especially in view of the fact that they are stated by the investigators to be "preliminary," can as yet hardly be taken as of general application to all rocks, even if correct for the specimen of sandstone examined.*

In our own investigations the laboratory was maintained at a temperature of from 63° to 68° F. (17·2° C. to 20° C.), and a thorough investigation into the effect of temperature was not undertaken, as this would be very difficult to carry out when employing the method of direct compression used, the difficulty consisting in heating the specimen itself without in any way affecting the measuring apparatus attached to it.

It seemed, however, possible to ascertain whether any serious change in the elastic constants of the massive crystalline rocks employed in the present investigation would result from a moderate change of temperature. For purposes of trial the rock selected was the Sudbury diabase, a typical fine-grained plutonic rock. A column of it was placed by Mr. McKergow in a small testing machine, having a capacity of 50 tons, and the temperature of the room in which the machine was set up having been lowered to +10° F. a cycle of compression readings was taken in the usual way adopted when Young's modulus is to be determined. The temperature of the room was then raised by about 10° and another cycle of readings was taken. It was then raised another 10° and a third series of readings was obtained, and so on through successive stages of 10° until the normal temperature of the room (about 65° F.) was reached. The initial reading of the instrument before the application of pressure was of course different in each case, owing to the expansion of the rock which followed from heating. These initial points were plotted on a line, and the results obtained when this specimen was subjected to a certain maximum load, together with the increase of temperature at each stage, were plotted on a second line. If the compression was greater at 65° than at 10° for the same load, these two lines should have diverged, but as a matter of fact they were

*In two very interesting papers, received while the present paper was in press (Modulus of Elasticity of Rocks and some inferences relating to Seismology, Journal of College of Science, Imperial University of Japan, vol. xx, article 9, 1905; and Kinetic Measurements of the Modulus of Elasticity, etc., ditto, vol. xx, article 10, 1905), Kusakabe shows that the presence of moisture in a rock has a very marked influence in diminishing its modulus of elasticity. This influence, he has ascertained, is very much more pronounced in the case of porous rocks—such as sandstone—which absorb a large quantity of water, than in the case of the compact crystalline rocks. He suggests that the effect, which in the paper above mentioned was attributed to heat, may really be due to the presence of moisture. He is now engaged in investigating the influence of moisture combined with a high temperature upon the modulus of elasticity of various rocks.

practically parallel. The differences between the readings given by the same load at different temperatures were no greater than those obtained by different measurements under the same load at the same temperature. The conclusion therefore seems to be indicated that a change of temperature made no perceptible difference within the range of temperatures employed, although a difference of 0·5 per cent. for each degree centigrade would mean a difference of about 25 per cent in range of temperature employed by Mr. McKergow.

While therefore this experiment cannot be considered as supplying accurate information concerning the effect produced by a rise in temperature on the elastic constants of rocks, for the instruments themselves are in some measure affected by

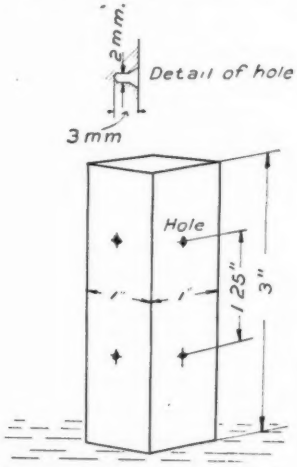

FIG. 4. Square test specimen of rock.

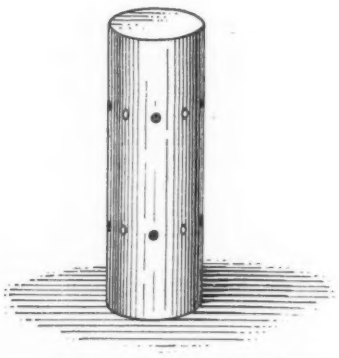

FIG. 5. Round test specimen.

the same changes of temperature, yet they serve to show that in the case of the massive crystalline rocks, the influence of temperature is probably not very great.

The Method of Measurements.

In carrying out the measurements, prisms of the rock 1 inch square and 3 inches long were usually employed (see fig. 4). These were cut and ground with smooth faces but were not polished. In these two small round holes were drilled in the medial line of each vertical face for the purpose of attaching the instrument, when Young's modulus was to be measured. These holes were made by means of a small diamond drill and were perfectly round and smooth. They were each 0·05 to

0·08 inch in diameter and 0·125 inch deep and 1·25 inches apart, lying at equal distances above and below the center of the prisms. These holes were chamfered at the outer end as shown in figure 4, and were found to afford the most perfect attachment which could be secured for the points of the instrument.

By means of these prisms two sets of measurements of the vertical compression could be made with each prism, by attaching the instrument first to one pair of opposite faces and then to the other.

In some cases round columns were used (see fig. 5). These were approximately 1 inch in diameter and 3 inches in length. With these it was possible to make four sets of measurements in compression with each column, by drilling eight pairs of holes as above described, whose plains intersected at angles of 45° instead of 90° as in the square prisms.

It was of course necessary in every case, whether prisms or columns were employed, to exercise great care to have the end of the test pieces very carefully faced and absolutely parallel to one another. Before the actual measurements were made, the rock in every case was brought to a "state of ease" in the manner already described.

The pressure was applied in most cases by a 100-ton Wickstead testing machine, which was so carefully adjusted that it was sensitive to a load of 4 pounds.

The specimen having been placed in the testing machine and brought to a state of ease was then after careful adjustment submitted to loads increasing in successive stages of 1,000 pounds until the limit of safety had been reached, when the load was reduced successively by the same amounts, accurate readings being taken at each increment and decrement of load. The maximum load employed in the case of most rocks was 9,000 pounds, equivalent to from 9,000 pounds to about 11,500 pounds per square inch according to whether a square or round prism was employed. In the case, however, of some of the stronger rocks a load of as much as 15,000 pounds per square inch was employed.

In the determination of the lateral strain, which was made upon the same columns as those used for measuring the vertical compression, care was taken that the theoretical conditions were realized, and that the material was free to expand laterally, as otherwise the values obtained for the lateral extension would be inaccurate. In all cases, therefore, the measuring apparatus was set as nearly as possible upon the central section of the test piece, and the ends of the specimen, after being ground smooth, were coated with a thin film of oil, so that the polished pressure plates of the machine would have as little tendency as possible to prevent freedom of lateral expansion.

It was found that these precautions being observed, the expansion at the ends of the column was practically as great as at the center where the measurement was taken; the difference being so small that no serious discrepancy was introduced.

In a number of cases accurate measurements were taken during the successive cycles of loading and unloading to which the specimen was subjected in order to bring it to a state of rest. These were recorded in the case of the Baveno granite and the Stanstead granite and serve to show how the hysteresis of the rock may be reduced to a minimum by subjecting the test-piece to this treatment. The measurements of each cycle usually occupied from ten to fifteen minutes.

In the case of a majority of the rocks investigated, a number of prisms or columns cut from the same block of rock were measured in order to ascertain whether different test pieces would give identical readings. It was found as a result of these investigations that the differences between the different specimens were no greater than those which were obtained by measuring the same specimens with the instrument attached to different sides.

In the case, however, of the Quincy granite, test pieces from two different blocks of the rock were prepared, and it was found that while the several measurements made on each test piece agreed among themselves, there was a distinct divergence in the elastic constants of the two specimens of the rock. This was probably due to a difference in composition, as the two rocks differed somewhat in appearance.

In the case of the green gabbro from New Glasgow, the results obtained by measurements made upon different parts of the same prism were discordant for reasons which will be pointed out and which were dependent upon the structure of the rock.

Fifty-five columns of rock, nineteen of glass, and two of iron were employed in this investigation and every precaution was taken to insure the attainment of accurate results. The rocks in all cases were air-dry, having been allowed to remain in the laboratory for several weeks after they had been cut, before the measurements were made.

In the accompanying tables the following elastic constants are given:

E=Young's Modulus, i. e., the quotient of the longitudinal stress by the longitudinal compression.

σ=Poisson's Ratio. This is the reciprocal of m.

D=Modulus of Cubic Compression $= \frac{1}{3}\left(\frac{m}{m-2}\right)E$. The reciprocal of this gives the decrease in volume of a cubic inch of the material for a pressure of 1 pound per square inch applied on every side.

C=Modulus of Shear=$\frac{1}{2}\left(\frac{m}{m+1}\right)E$, which is the quotient of torsional stress to torsional strain.

m=The ratio of longitudinal compression to lateral extension per unit of length.

E and m are measured directly; the other values are calculated from them.

These values in the case of each rock are given in inch and pound units, and the results are summarized in a general table on page 121. The measurements were made in these units on account of the fact that the testing machine employed was graduated to read pounds.

For purposes of comparison, however, this latter table has been recalculated in C.G.S. units, and the results are set forth in the second table, to be found on page 121.

In the case of metal, Poisson's ratio is generally arrived at by stretching the bar and determining the value of the longitudinal extension divided by the lateral contraction. In case of rocks the tensile strength being low and the materials being brittle, it is more convenient and more accurate to make the determination by compressing a short bar or column, and determining the value of the longitudinal compression divided by the lateral expansion. This gives the value designated as m, of which Poisson's ratio is the reciprocal. Theoretically one method is as accurate as the other.

In each table the first transverse line designates the specimen employed as *a*, *b*, *c*, or *d*.

The second line gives the diameter of the specimen, which is often slightly different in the two directions. The length of the column in all cases was about three inches, but this is not stated in the table, as the compression is not measured on the total length of the column, but on the length of that portion of it which lies between the points of attachment of the instrument.

The third line gives the area, which is approximately one square inch in the case of a square prism and three-quarters of a square inch in the case of a round column.

The fourth transverse line contains the letters U or P, which designate the two diameters of the column when two measurements were made on the same square prism; these two directions being always at right angles to one another. In the case of round columns on which measurements were frequently made in several planes, these are designated as "first holes," "second holes," etc.

In the four succeeding lines the four elastic constants E, σ, D and C are given as determined by each measurement.

The sixteen rocks whose elastic constants were determined are enumerated in the following list:

Marbles and Limestones.

1. Black Belgian marble; an extremely fine-grained and massive black marble, largely used for ornamental purposes and known in trade as "Belgian Black".

2. White marble, Carrara, Italy; a typical fine-grained saccharoidal marble.

3. White marble, Vermont, U. S. A.; identical in appearance with the last.

4. Pink marble, Tennessee, U. S. A.; a highly metamorphosed coralline limestone which has been converted into a marble; largely used for purposes of construction and known as "Pink Tennessee."

5. Trenton limestone, Montreal, Canada; a highly fossiliferous variety, free from any signs of stratification, taken from a heavy bed in the Mile End quarries at this place; used extensively as a building stone.

Granites.

6. Granite, Baveno, Italy; a typical biotite granite of medium grain.

7. Granite, Peterhead, Scotland; a typical, rather coarse-grained, biotite granite.

8. Granite, Lily Lake, New Brunswick, Canada; closely resembles No. 7.

9. Granite, Westerly, Rhode Island, U. S. A.; a typical, very fine-grained reddish biotite granite.

10. Granite, Quincy, Massachusetts, U. S. A.; a rather coarse-grained hornblende pyroxene granite.

11. Granite, Stanstead, Quebec, Canada; a rather fine-grained muscovite biotite granite; the mica is relatively more abundant than in either the Peterhead or the Westerly granites.

Nepheline Syenite.

12. Nepheline syenite, Montreal, Canada; a typical fine-grained massive hornblende nepheline syenite.

Basic Plutonic Rocks.

13. Anorthosite, New Glasgow, Quebec, Canada; a rock composed of plagioclase with a subordinate amount of pale green augite and green hornblende; it is fine in grain and very tough, being used for paving sets in the city of Montreal.

14. Essexite, Mount Johnson, Quebec, Canada; a typical essexite, massive and uniform in character, composed of plagioclase, nepheline, augite, hornblende and biotite; used extensively as a building stone and for monuments.

15. Gabbro, New Glasgow, Quebec, Canada; this rock is deep green in color and occurs in the form of a large dike cutting the anorthosite (No. 13); composed of augite, hornblende and plagioclase, the two former minerals preponderating largely. It

shows a distinct parallelism in the arrangement of the constituents, to which may be attributed a considerable divergence in the results obtained in the different measurements of the elastic constants.

16. Olivine diabase, near Sudbury, Ontario, Canada; a typical fine-grained, perfectly massive olivine diabase, occurring as a large dike cutting rocks of Huronian age.

Sandstones.

17. Sandstone, Cleveland, Ohio, U. S. A., a fine, even-grained yellowish sandstone, extensively used for building purposes. The bedding is marked by a slight variation in the color of the different beds. The prism used in the measurement of the elastic constants was cut from a single bed and was taken parallel to the plane of bedding.

A summary of the results obtained in the measurement of the elastic constants of these rocks is given on p. 121. The extended results are here presented in the case of three rocks only, which may serve as representatives of the others.

Carrara Marble:

Three specimens of the rock were used in measuring the elastic constants, two squares prisms (*a* and *b*) and a round column (*c*). Two sets of measurements were made on both *b* and *c*, the instrument as usual being affixed to the specimens in two positions at right angles to one another in each case. In this way five sets of measurements were made. The results are set forth in the following table:

Carrara Marble

No.	*a*	*b*	*b*	*c*	*c*
Size	1·032×1·035	1·017×1·016	----	·985	·985
Area	1·07	1·033	1·033	·762	·762
E	8,120,000	7,800,000	8,055,000	8,210,000	8,045,000
σ	·281	·274	·273	·275	·269
D	6,170,000	5,750,000	5,920,000	6,100,000	5,790,000
C	3,170,000	3,060,000	3,160,000	3,210,000	3,170,000

The averages of the results obtained for the respective constants are as follows:—

E=8,046,000; σ=0·2744; D=5,946,000; C=3,154,000.

The difference between the highest and lowest determinations of D is 420,000 pounds.

Figure 6 shows the stress strain curves plotted from the results obtained from specimen *a*, the ordinates representing the load (stress) and the abscissae the amount of the strain. I

represents in all cases the longitudinal compression and II the lateral extension. The hysteresis is greater than in the case of the black Belgian marble (fig. 7), but about the same in amount as shown by the Vermont marble and the Trenton limestone from Montreal.

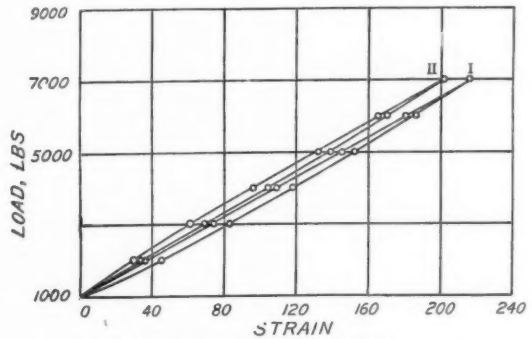

FIG. 6. Carrara Marble, stress strain curves.

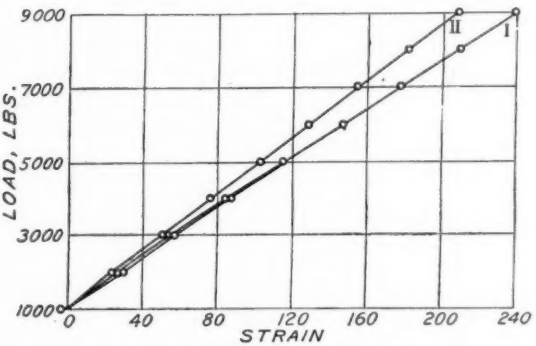

FIG. 7. Black Belgian marble, stress strain curves.

Granite, Westerly, Rhode Island, U. S. A.

Four test pieces were used in measuring the elastic constants, viz: two square prisms, *a* and *b*, and two round columns, *c* and *d*. Two sets of determinations were made on each of the first three specimens, the instruments being attached to different pairs of sides in each case, and four sets of determinations were made on specimen *d* in planes making angles at 45° with one another. The results are given in the following table.

The averages of the values obtained are as follows:

$E = 7{,}394{,}500$; $\sigma = \cdot 2195$;
$D = 4{,}397{,}500$; $C = 3{,}019{,}700$

The difference between the highest and lowest values in the four determinations of D on specimen d was only 280,000.

Of the other columns a gave on an average somewhat lower and b somewhat higher results.

The stress strain curves obtained from specimen a are shown in figure 8. The hysteresis is greater than that shown in the case of any of the other granites except that from Stanstead.

In figure 9 the stress strain curves for the Peterhead granite, and in figure 10 those for the nepheline syenite are shown for purposes of comparison.

Olivine Diabase, near Sudbury, Ontario, Canada.

Four test pieces were used in determining the elastic constants of the rock, viz: three round columns and one nearly square prism. They are designated as a, b, c and d. The three round columns were cut out of a block of the diabase by means of an annular diamond drill. Two measurements were made on each of these in planes at right angles to one another, in each case, while four measurements were made on the prism d using two pairs of faces. In this way ten complete sets of measurements were made for the elastic constants of this diabase.

The values obtained are given in the tables on p. 117.

As will be seen, the values obtained for D in this rock are considerably higher than those yielded by any other rock of the series examined. In the six independent measurements carried out on the first three specimens, the difference between the highest and lowest values for D amounted to 830,000 pounds, while on the four measurements made on specimen d there is a rather greater difference amounting to 845,000 pounds.

Granite, Westerly, Rhode Island, U. S. A.

No.	a	a	b	b	c	c	d	d	d	d
Size	1·008×1·002	----	·981×·929	----	·975	----	·975	----	----	----
Area	1·01	----	·91	----	·75	----	·75	----	----	----
Side	*U.*	*P.*	*U.*	*P.*	1st holes	2d holes	1st holes	2d holes	3d holes	4th holes
E	7,180,000	7,090,000	7,625,000	7,745,000	7,670,000	7,335,000	7,575,000	7,335,000	7,170,000	7,250,000
σ	·21	·1985	·241	·214	----	----	·225	·223	·2225	·222
D	4,110,000	3,950,000	4,925,000	4,515,000	----	----	4,600,000	4,420,000	4,320,000	4,340,000
C	2,970,000	2,960,000	3,070,000	3,185,000	----	----	3,090,000	2,980,000	2,940,000	2,961,000

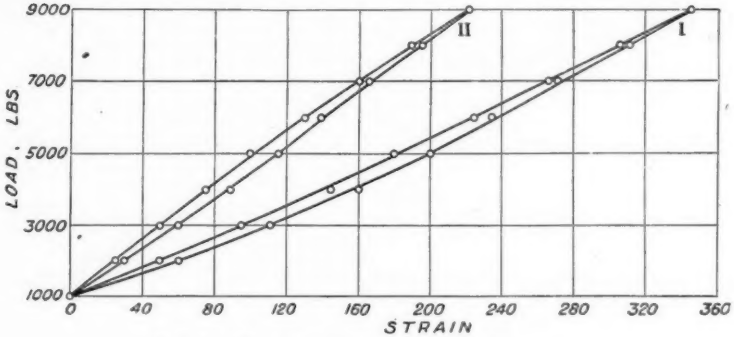

FIG. 8. Westerly granite, stress strain curves.

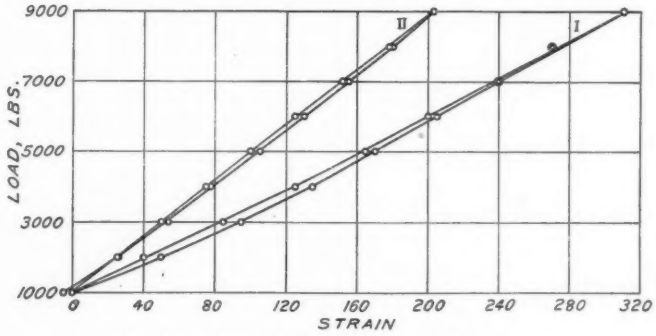

FIG. 9. Peterhead granite, stress strain curves.

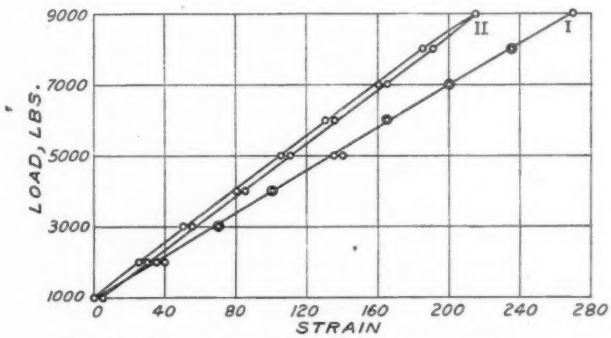

FIG. 10. Montreal nepheline syenite, stress strain curves.

The averages of the determinations made on each of the columns are as follows:

	E	*D*	σ	*C*
a =	13,515,000	10,400,000	0·2838	5,270,000
b =	14,170,000	10,945,000	·2840	5,525,000
c =	14,170,000	11,085,000	·2870	5,505,000
d =	13,197,750	10,076,000	·2812	5,155,000
Av.	13,763,187	10,626,500	·2840	5,363,750

The stress strain curves given by this rock are shown in figure 11. As will be seen from these curves, in its approach to perfect elasticity the rock is comparable to plate glass.

The Elastic Constants of Glass.

As in geophysical speculations, the earth in respect to its rigidity and compressibility is often compared to a globe of glass, it seemed advisable to determine as accurately as possible the elastic constants of glass, for the purpose of comparing them with the results obtained in the case of the various rocks considered in this paper, employing the same methods and carrying out the work under exactly the same conditions. This material lends itself excellently to this method of measuring these constants, provided the glass is free from all irregularities in its substance and is isotropic in character. The first difficulty experienced was that of obtaining such a glass. At the outset it was thought that thick glass rods such as are used for various purposes in the chemical and physical laboratory might be employed, but although several lots of the purest variety of this material were procured, the glass constituting it was found in all cases to contain minute air bubbles, and when examined between crossed nicols in polarized light, showed brilliant colors—red, yellow and blue. This indicated a state of marked tension in the glass, evidently due to the rod having been drawn when the glass was in a viscous state, which was also shown by the circular arrangement of the little bubbles in the rod, following the direction of its surface. Short lengths of this rod moreover when tested in compression, so soon as the maximum load had

Olivine Diabase, Sudbury, Province of Ontario, Canada.

No.	*a*	*a*	*b*	*b*	*c*	*c*	*d*	*d*	*d*	*d*
Size	·981	·981	·983	·983	·983	·983	1·000×·864	----	----	----
Area	·756	·756	·758	·758	·758	·758	·864	·864	·864	·864
E	13,250,000	13,780,000	14,020,000	14,320,000	14,020,000	14,320,000	13,150,000	13,330,000	13,450,000	12,860,000
σ	·2865	·281	·291	·277	·291	·283	·276	·285	·287	·279
D	10,340,000	10,460,000	11,170,000	10,720,000	11,170,000	11,000,000	9,810,000	10,340,000	10,500,000	9,655,000
C	5,160,000	5,380,000	5,430,000	5,620,000	5,430,000	5,580,000	5,170,000	5,200,000	5,230,000	5,020,000

Plate Glass.

No	*a*	*b*	*c*	*d*	*e*	*f*	*g*
Size	0·9855×1·0205	0·9865×1·0055	0·981×1·0135	1·016×1·008	1·0215×0·9955	1·022×1·0025	1·025×0·994
Area	1·0057	0·992	·994	1·024	1·017	1·024	1·016
E	10,350,000	10,950,000	10,480,000	10,380,000	10,450,000	10,380,000	10,450,000
	10,590,000	10,500,000	10,350,000	10,380,000	10,930,000	10,600,000	10,230,000
σ	0·2281	0·236	0·226	0·233	0·221	0·229	0·216
	0·228	0·2341	0·235	0·227	0·23	0·225	0·215
D	6,370,000	6,930,000	6,460,000	6,480,000	6,380,000	6,370,000	6,140,000
	6,480,000	6,580,000	6,520,000	6,350,000	6,760,000	6,430,000	6,020,000
C	4,220,000	4,440,000	4,280,000	4,210,000	4,280,000	4,220,000	4,300,000
	4,310,000	4,250,000	4,190,000	4,230,000	4,440,000	4,330,000	4,360,000

been exceeded, instead of splitting from top to bottom, broke as if composed of a series of rudely concentric shells.

After a prolonged search for isotropic glass in masses of sufficient size to measure the elastic constants, it was found that plate glass answered the requirements. A piece of one inch plate glass, made in Great Britain, was accordingly secured and was cut into strips an inch wide, and these again into three inch lengths. The square prisms thus produced were then properly faced and polished. The glass was found to be absolutely free from all flaws and impurities, and when examined between crossed nicols, the prisms although an inch thick, showed in one direction at right angles to vertical axis absolute blackness throughout a complete revolution, while in the other direction at right angles to this there was during a revolution an alternation of blackness with a pale grayish illumination. This change was so slight that considering the thickness of the glass and the sensitiveness of the test, the material may be considered to be practically free from internal tension, and to be isotropic in character.

In order to get a good average and to eliminate chance errors so far as possible, seven of these prisms were taken, and two complete sets of determinations were made on each of them, using in every case different pairs of faces. Fourteen determinations were thus made of each of the elastic

constants. The figures obtained are set forth in the table on p. 118.

In this table a complete series of values obtained from each specimen are given in double rows. When the average of all these results is taken, the values obtained for the several constants of plate glass are as follows:

$E = 10{,}500{,}000$; $\sigma = 0{\cdot}2273$; $D = 6{,}448{,}000$; $C = 4{,}290{,}000$

The stress-strain curves given by one of the prisms is shown in figure 12. In this figure I represents longitudinal compression and II lateral extension.

Determinations of the cubic compressibility of glass, D, have been made by other observers using various methods.

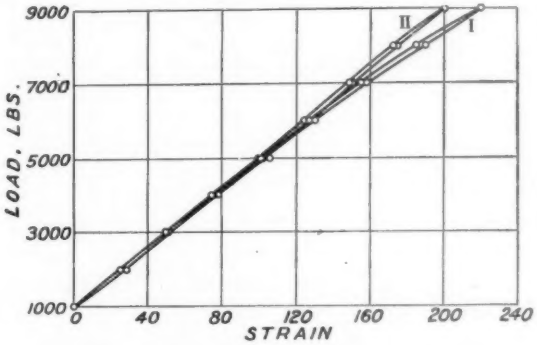

FIG. 11. Sudbury Diabase, stress strain curves.

The results go to show that different varieties of glass vary considerably in their compressibility. These determinations may be tabulated as follows:*

Everett	5,074,600 to 6,379,400	(C.G.S. $= 3{\cdot}5$ to $4{\cdot}4 \times 10^{11}$)
Amagat-common glass	6,745,000	(·000002181 per atmosphere)
Amagat-crystal glass	6,112,300	(·000002405 " ")
Tait	5,657,700	(·0000026 " ")

As will be seen, the figures obtained for plate glass in the present investigation lie a little above the average of the various values here given, and are nearly those of the highest value obtained by Everett.

* See Everett, Illustrations of the C.G.S. System of Units with tables of Physical Constants. Macmillan & Co., 1902, pp. 60 to 64. The figures there expressed in various units have been here recalculated into inch-pound values.

Summary of Results.

In the table on the following page a summary is shown of the average values obtained for E, σ, C and D in the case of all the rocks examined in this investigation. Together with these are placed for purposes of comparison the results obtained for these constants in the case of wrought iron, cast iron and glass. In the second table these values are again presented, recalculated into C.G.S. units.

The rocks fall naturally into three groups differing from one another in compressibility, but the several members of each group agreeing fairly closely among themselves.

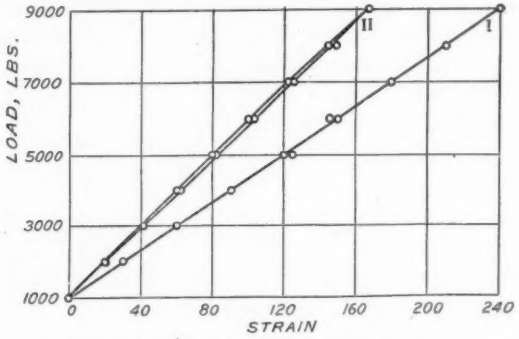

FIG. 12. Plate glass, stress-strain curves.

These three groups show a corresponding difference in composition.

The first group consists of the marbles and limestones. These have an average value for D of 6,345,000. One of these, however, the Black Belgian marble, which is very much finer in grain than the others, and breaks almost like a piece of glass, has a very much higher value for D than that possessed by the other rocks, which among themselves are nearly identical. If we omit this Belgian marble, the average of D for the other limestones and marbles is 5,855,000.

The second group comprises the granites. These again show a close agreement of values among themselves, except in the case of the Stanstead granite, which rock as already mentioned shows a defective elasticity. The average value of D for the granites is 4,399,000.

The third group embraces the basic intrusives (gabbro, anorthosite, essexite and diabase). These show greater differences, but have an average value for D of 8,825,000. The nepheline syenite, although higher in silica and therefore properly speaking an acid rock, in its freedom from quartz and its richness in feldspar (although the feldspar is largely orthoclase instead of plagioclase), in mineralogical composition

belongs with these basic rocks rather than with the granites. It also approaches the essexite most nearly in its compressibility.

ELASTIC CONSTANTS OF ROCKS.

Summary of Results (average) expressed in Inch-Pound Units.

	E	σ	C	$D=\frac{1}{3}\left(\frac{m}{m-2}\right)E$
Wrought iron	28,100,000	0·2800	11,000,000	21,300,000
Cast iron	15,000,000	0·2500	6,000,000	10,000,000
Black Belgian marble	11,070,000	0·2780	4,330,000	8,303,000
Carrara marble	8,046,000	0·2744	3,154,000	5,946,000
Vermont marble	7,592,000	0·2630	3,000,000	5,341,000
Tennessee marble	9,006,000	0·2513	3,607,000	5,967,000
Montreal limestone	9,205,000	0·2522	3,636,000	6,167,500
Baveno granite	6,833,000	0·2528	2,724,800	4,604,000
Peterhead granite	8,295,000	0·2112	3,399,000	4,792,000
Lily Lake granite	8,165,000	0·1982	3,380,000	4,517,500
Westerly granite	7,394,500	0·2195	3,019,700	4,397,500
Quincy granite (1)	6,747,000	0·2152	2,781,600	3,984,000
Quincy granite (2)	8,247,500	0·1977	3,445,000	4,555,000
Stanstead granite	5,685,000	0·2585	2,258,700	3,940,000
Nepheline syenite	9,137,500	0·2560	3,635,000	6,237,500
New Glasgow anorthosite	11,960,000	0·2620	4,750,000	8,368,000
Mount Johnson essexite	9,746,000	0·2583	3,872,600	6,750,000
New Glasgow gabbro *	15,650,000	0·2192	6,365,000	9,555,000
Sudbury diabase	13,763,000	0·2840	5,364,000	10,626,500
Ohio sandstone	2,290,000	0·2900	888,000	1,816,000
Plate glass	10,500,000	0·2273	4,290,000	6,448,000

Summary of Results (average) expressed in C.G.S. Units.

	E	σ	C	$D=\frac{1}{3}\left(\frac{m}{m-2}\right)E$
Wrought iron	$19{\cdot}37\times10^{11}$	0·2800	$7{\cdot}590\times10^{11}$	$14{\cdot}680\times10^{11}$
Cast iron	$10{\cdot}34\times10^{11}$	0·2500	$4{\cdot}132\times10^{11}$	$6{\cdot}897\times10^{11}$
Black Belgian marble	$7{\cdot}24\times10^{11}$	0·2780	$2{\cdot}982\times10^{11}$	$5{\cdot}736\times10^{11}$
Carrara marble	$5{\cdot}54\times10^{11}$	0·2744	$2{\cdot}171\times10^{11}$	$4{\cdot}090\times10^{11}$
Vermont marble	$5{\cdot}24\times10^{11}$	0·2630	$2{\cdot}069\times10^{11}$	$3{\cdot}680\times10^{11}$
Tennessee marble	$6{\cdot}21\times10^{11}$	0·2513	$2{\cdot}482\times10^{11}$	$4{\cdot}115\times10^{11}$
Montreal limestone	$6{\cdot}35\times10^{11}$	0·2522	$2{\cdot}504\times10^{11}$	$4{\cdot}250\times10^{11}$
Baveno granite	$4{\cdot}71\times10^{11}$	0·2528	$1{\cdot}875\times10^{11}$	$3{\cdot}178\times10^{11}$
Peterhead granite	$5{\cdot}71\times10^{11}$	0·2112	$2{\cdot}340\times10^{11}$	$3{\cdot}300\times10^{11}$
Lily Lake granite	$5{\cdot}63\times10^{11}$	0·1982	$2{\cdot}330\times10^{11}$	$3{\cdot}103\times10^{11}$
Westerly granite	$5{\cdot}09\times10^{11}$	0·2195	$2{\cdot}080\times10^{11}$	$3{\cdot}029\times10^{11}$
Quincy granite (1)	$4{\cdot}64\times10^{11}$	0·2152	$1{\cdot}916\times10^{11}$	$2{\cdot}750\times10^{11}$
Quincy granite (2)	$5{\cdot}68\times10^{11}$	0·1977	$2{\cdot}373\times10^{11}$	$3{\cdot}140\times10^{11}$
Stanstead granite	$3{\cdot}92\times10^{11}$	0·2585	$1{\cdot}556\times10^{11}$	$2{\cdot}718\times10^{11}$
Nepheline syenite	$6{\cdot}29\times10^{11}$	0·2560	$2{\cdot}505\times10^{11}$	$4{\cdot}290\times10^{11}$
New Glasgow anorthosite	$8{\cdot}25\times10^{11}$	0·2620	$3{\cdot}275\times10^{11}$	$5{\cdot}760\times10^{11}$
Mount Johnson essexite	$6{\cdot}71\times10^{11}$	0·2583	$2{\cdot}670\times10^{11}$	$4{\cdot}650\times10^{11}$
New Glasgow gabbro *	$10{\cdot}80\times10^{11}$	0·2192	$4{\cdot}380\times10^{11}$	$6{\cdot}589\times10^{11}$
Sudbury diabase	$9{\cdot}49\times10^{11}$	0·2840	$3{\cdot}700\times10^{11}$	$7{\cdot}329\times10^{11}$
Ohio sandstone	$1{\cdot}58\times10^{11}$	0·2900	$\cdot612\times10^{11}$	$1{\cdot}250\times10^{11}$
Plate glass	$7{\cdot}24\times10^{11}$	0·2273	$2{\cdot}960\times10^{11}$	$4{\cdot}439\times10^{11}$

If the nepheline syenite be included with the basic rocks, an average value of D is obtained of 8,308,000.

This omits from consideration the sandstone, it being a rock

* See page 112.

of an entirely different class from the others, and furthermore one which shows so much hysteresis that the application of this method to it is less satisfactory than in the case of the other rocks of the series.

These results may be presented as follows:

	Average of D
Marbles and limestones	6,345,000
Granites	4,399,000
Basic intrusives	8,308,000

The cause of the much greater compressibility of granite as compared with the marbles and basic intrusives is not clear, but would seem to be connected with the presence of quartz. The only determination of the cubic compressibility of quartz, so far as can be ascertained, is one by Voigt,* the value obtained being 5,504,190 pounds (387×10^6 grams per. sq. cent.). This compressibility, as will be seen, is much greater than that found in the case of either the limestones or the basic intrusives, and while not in itself sufficiently great to account for the high compressibility of the granites, goes to show that in the quartz we have a mineral which is more compressible than the ordinary rock-making minerals which form the chief constituent in the rocks of the series examined.

The marbles and the limestones of the earth's crust are confined to its most superficial portion, resulting as they do from the process of sedimentation. There is every reason to believe, however, that what we may term the sub-structure of the earth's crust is composed of acid and basic plutonic igneous rocks. These make up the lowest part of the crust to which we have access, and are found coming up from the still greater depths.

The cubic compressibility, D, of the earth's crust must lie between the values given above for the granites and the basic intrusives, approaching one or other of these values according to the relative proportion in it of one or other of these classes of rocks.

If we take the average of the values obtained from these two classes of rocks as represented by the seven granites and the five basic intrusives (including the nepheline syenite), the value obtained for D is 6,353,500.

This, as will be seen, differs but little from the value of D obtained for plate glass, which is 6,448,000.

If, therefore, the earth's crust be composed of granite and basic igneous rocks in approximately equal proportions, its compressibility will be that of glass. If it be composed almost exclusively of granite, the earth's crust will be more compressible than glass; and if the basic rocks preponderate very largely, it will be less compressible than this substance.

* Quoted in Becker, Experiments on Schistosity and Slaty Cleavage, Bulletin 241, U. S. Geol. Survey, p. 32.

It is, however, in any case much more compressible than steel, which has a value for D of from 26,098,000 to 27,547,000 (18 to 19×10^{11}, C.G.S.)*.

The compression to which the rocks were subjected in this investigation ranged from 6,000 to 17,340 pounds to the square inch. Most of the rocks, however, were subjected to a load of from 9,000 to 15,000 pounds per square inch, and their bulk compression was determined for these loads as maxima. Higher pressures could not be employed without incurring the risk of breaking the specimen, and at the same time of destroying the measuring apparatus. One apparatus was in fact so destroyed.

The question arises as to whether under still higher pressures, if rupture could be avoided, the ratio of load to compression would be maintained. Judging from the deportment of much stronger substances, such as steel, when similarly tested, it is inferred that this ratio of bulk compression will remain constant for very much higher pressures, or until deformation sets in and the rock begins to flow.

With regard to the accuracy of the results obtained by this method as compared with those obtainable by any method in which cubic compression is actually produced and measured, it may be observed that by far the best method of this kind hitherto suggested seems to be that proposed by Richards and Stull.† We have endeavored to make use of this method in order to obtain results for purposes of comparison with those given in the present paper, but have not hitherto succeeded in overcoming certain experimental difficulties. The experimental errors in this method, though apparently small, still exist, and in applying it to rocks, which are much less compressible than the substances examined by Richards and Stull, these errors become proportionately more serious. Moreover, higher pressures than those used in the method employed in the present paper could scarcely be employed in this direct method, while difficulties dependent on the possible lack of absolute continuity in the substance of the rock and the danger of minute air-filled spaces, would probably present themselves in the case of most rocks. It seems that all things being considered, the indirect method here employed is probably as accurate as any direct method which can be used. The attempt to apply Richards and Stull's method to the same rocks is still being continued, however, and it is hoped that satisfactory results may be eventually obtained by its use.

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* Illustrations of the C.G.S. System of Units with tables of Physical Constants. Macmillan & Co., 1902, p. 60.

† New method of Determining Compressibility. Published by the Carnegie Institution, Washington, D. C., Dec., 1903 (No. 7).

Art. XII.—*The Dakotan Series of Northern New Mexico;* by Charles R. Keyes.

Strata that have been referred to the Dakota division of the Cretaceous age have been long known in the Southwest, around the southern end of the Rocky Mountains in northern New Mexico. The section there exposed has been generally regarded as exactly representing the "Dakota Group" as first defined by Meek and Hayden* for the upper Missouri region. Late observations in the New Mexican region indicate clearly that the formation called the Dakota sandstone has never been carefully delimited, that it has been given quite different limits by different authors, and that the section usually so called actually belongs to several geological ages.

As recently made out, the general Mesozoic section of northeastern New Mexico presents the following elements:

General Mesozoic Section of Northeastern New Mexico.

Age.		Series.	Thickness.
Cretacic	Late	7. Laramian sandstones	2500
		6. Montanan shales	1600
	Mid	5. Coloradan shales	1000
		4. Dakotan sandstones	500
	Early	3. Comanchan shales	100
Jurassic		2. Morrisonian sandstones	250
Triassic		1. Red Beds (upper part)	1000

As usually considered in the literature of the subject, the Dakota sandstone has been made to cover of the above section not only No. 4, but No. 2 and No. 3, and not infrequently part of No. 1. The reasons for these long standing errors of interpretation recalls one of the unpleasant chapters in the history of American geology. It goes back to the very beginning, to the early sixties, when there was a concerted attempt to thoroughly discredit the work of Jules Marcou in this country. The proofs of the conclusions which the Swiss geologist submitted may have been insufficient at the time, or they may have been happy guesses, but the fact yet remains that the latest work in the region has, in the main, substantiated his observations and there are too many of his statements that are correct to assert at this day that they were anything less than a display of geological acumen such as none of his critics possessed. Newberry, Hayden, Meek and others appear to have become so absorbed in their side of the controversy that they all but lost sight of the facts, and they not infrequently went

* Proc. Acad. Nat. Sci., Phila., vol. xiii, pp. 410–420, 1862.

so far as to discuss in the most positive manner sections which they had never been near. Instead of clearing up the points under discussion, this long drawn out controversy only served to make the entire question more obscure.

When I was first suddenly made acquainted with the Cretaceous formations of the region, it was in the field, before it was possible to consult carefully very much of the literature on the subject. In mapping and in local descriptions in the northern New Mexican province I assumed the Dakota sandstone to be the great massive plate of yellow sandstone about 500 feet in maximum thickness. Above it were the Colorado shales and beneath in many places a peculiar succession of sandy shales, shaly sandstones and clay shales. Several papers were even published on New Mexican geology in which this idea of the Dakota formation of the region was expressed. The chief reasons for considering this great plate as a formation by itself and as representing the Dakota sandstone were (1) that it immediately underlay the Colorado shales, which were well identified by numerous fossils, and (2) that the sandstone rested in marked unconformity upon the formations beneath. When, later, the literature was gone over carefully in order to compare the published observavations of others with my own, it was with much surprise that I found that prevailing opinions included in the Dakota section a much greater sequence than I had done. This led immediately to a detailed examination of many of the more critical of the described sections; and the location of the real difficulties of former interpretations.

The use of the term Dakotan series for the sequence of massive yellow sandstones which form the bottom of the Cretaceous section over the greater part of New Mexico is based upon the accepted terminology of the general Mesozoic section of the Rocky Mountain region. As a definite geologic title the name Dakota was first applied by Meek and Hayden,* in 1862, to the basal member of the Cretaceous of the Upper Missouri River district. Although included in their "Earlier Cretaceous" division, this is not the Early Cretaceous division as at present understood, but is the base of what has long been known as the "Upper Cretaceous." In the general geological section the formation belongs properly to the Mid Cretaceous period.

As the entire succession of the Mid Cretaceous and Late Cretaceous formations is upturned along the eastern flank of the Rocky Mountains, the Dakotan division is readily traced from the original locality southward into central New Mexico, and the title given to the series in the north appears to be

* Proc. Acad. Nat. Sci., Phila., vol. xiii, pp. 510–520, 1862.

fully applicable to certain sandstones widely distributed in the south.

Many different titles have been given to the sandstones belonging to the Dakotan series; and the term itself has been used in many different senses by the various writers who have passed through the New Mexican field. Among the first to call attention to the formation in question was Jules Marcou,* who, as early as the year 1853, traversed this region in connection with an expedition sent out by the Federal government to survey a railroad route to the Pacific coast along the thirty-fifth parallel of latitude.

Capping Pyramid Mountain, Cerro Tucumcari and the cliffs of the Canadian river near the eastern border of New Mexico, Marcou noted about 50 feet of massive yellow sandstones which, with other underlying beds, he regarded as Jurassic in age. The massive yellow sandstone of these sections subsequently proved to be the attenuated eastern edge of what is now denominated the Dakotan series; while lately the age of the beds beneath was finally adjudged in accordance with Marcou's original designation.

During the year 1858 Newberry† crossed northern New Mexico and recognized an extensive development of rocks which he regarded as of Cretaceous age and which he divided into a lower group and an upper group. These divisions are not regarded as representing the similarly named subdivisions of the general Cretaceous section. In the "Lower" division, as thus understood, the Dakotan sandstones were included; and the terms so far as they apply to northeastern New Mexico may be considered as practically co-extensive. In northwestern New Mexico he embraced in this Lower division also the Jurassic Zunian beds. His "Lower Cretaceous" does not, as has been widely believed, correspond to Meek and Hayden's subdivision of the "Early Cretaceous." This is very clearly shown in his descriptions of the region around Las Vegas.‡ In the year following Newberry's return from the Colorado River of the West, and two years before the publication of his official report just referred to, this author published a criticism§ on Marcou's Jurassic system of New Mexico, in which he attempted to show that all of the so-called Jurassic rocks are really Cretaceous in age, and correspond to Meek and Hayden's Fort Benton and Niobrara groups, or the Coloradan series of present nomenclature. This, however, is not strictly correct. The larger part of Marcou's Jurassic system of rocks

* Exp. and Sur. Pacific R. R. Route, vol. iii, p. 137, 1856.
† Ives Rept. Colorado River of West, pt. iii, p. 107, 1861.
‡ Loc. cit., p. 106.
§ This Journal (2), vol. xxviii, pp. 298–299, 1859.

of the New Mexican region belongs to the Dakotan series, or below. The discussion is quite remarkable and, in the light of recent investigations, is strangely incongruent. Marcou and Newberry traversed very different routes; that of the first named explorer being up the Canadian river valley a hundred miles south of the old Santa Fe trail which the last mentioned observer followed. While Newberry was discrediting Marcou's recognition of Jurassic rocks, he himself passed over country where they were not present except at one point—at the Cimarron crossing; and years afterward,* with no reference whatever to his former contention, he assigned certain beds in this vicinity to a Jurassic age. Recently Stanton† finds that these and the Tucumcari beds of Marcou are continuous and form part of the Morrisonian series.

Newberry‡ in his later report subdivided the Cretaceous into three sections, the "Lower" division embracing only the Dakota sandstone.

Although Hayden,§ who with Meek originally defined the Dakota division of the Cretaceous, recognized his formation within the limits of New Mexico in traveling from Raton to Santa Fe, it is not possible to determine from his meager descriptions just how much of the general section of the region he intended to include under the title. However, it is known from the route which he followed that he had at no time any other than the main massive sandstone in view. At no point which he visited are any of the lower, or Morrisonian, beds exposed.

As originally described, the "Lower Cretaceous" of Stevenson,‖ of northeastern New Mexico, appears to embrace only what is now called the Dakotan series. In a later publication¶ this writer uses the terms "Dakota Group" to cover not only the Dakotan series, as at present understood, but also the Jurassic section, and a part of the underlying Triassic beds of previous writers. This group was subdivided by him into three sections called the Lower Dakota, the Middle Dakota and the Upper Dakota. The last mentioned alone can now be considered as the equivalent of Meek and Hayden's original Dakotan series. This author** says: "The grouping to be proposed is merely provisional; dependence has been placed

* Macomb's Expl. Exp. Junc. Grand and Green Rivers, p. 28, 1876.
† Journal of Geology, vol. xiii, pp. 657–669, 1905.
‡ Macomb's Expl. Exp. Geol. Rept., 121, 1877.
§ U. S. Geol. Surv. Terr., Third Ann. Rept., 2d ed., p. 162, 1873.
¶ Ibid., Supp., p. 90, 1881.
‖ U. S. Geol. Surv. W. 100 Merid., vol. iii, p. 400, 1975.
** Loc. cit., p. 88.

solely upon lithological characters and stratigraphy, since testimony of fossils is either unattainable or indecisive. When the work shall have been prosecuted in detail and carried systematically toward the south and west to localities already well determined by evidence of fossils, this classification may prove to be somewhat arbitrary. For the present, however, it seems desirable to include under one group the Dakota of Meek and Hayden and the greater part of the Triassic of authors found in New Mexico. The whole series may be Triassic or it may be wholly Cretaceous. It is included under the Dakota here merely for convenience of description."

It is quite clear from a consideration of the various localities mentioned that the author had somewhat mixed his stratigraphy, a fact not to be wondered at when the limited time he had for examination is taken into account. His "Upper Dakota" of one locality is the "Lower Dakota" of another. Elsewhere the latter is of undoubted Early Cretaceous age, and not Mid Cretaceous (Upper Cretaceous) at all.

So far as is known, it is largely due to this report that the confusion regarding the delimitation of the Dakotan series arose in this region. Although the Hayden reports make scant reference to the New Mexican region, the various allusions are of similar tone. And the way was paved by Newberry's denunciations of Marcou based upon very incomplete observations.

In northwestern New Mexico, Holmes* ascribes about 1,200 feet of strata to the Dakota group, which he divides into "Lower" and "Upper" portions. Only the massive Upper division is now regarded as properly representing the Dakotan series. The so-called "Lower Dakota" formation is quite different lithologically from the "Upper" portion, and Dutton† more recently gave it the name of Zuñi sandstones. It is now regarded as Jurassic in age, as already noted.

In later years Cummins‡ has proposed to put the attenuated Dakota sandstone, as exposed in the Cerro Tucumcari in eastern New Mexico, with the Early Cretaceous and Jurassic formations of that section, and to call the whole the Tucumcari beds, or formation.

The unity of the great sandstone plate as a distinct and easily recognizable stratigraphic formation seems to be now fully demonstrated, and also finds corroboration in the recent observations of Stanton in southeastern Colorado. The name Dakotan series is properly restricted to it.

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* U. S. Geol. and Geog. Sur. Terr., 9th Ann. Rept., p. 224, 1877.
† U. S. Geol. Sur., 6th Ann Rept., p. 140, 1886.
‡ Texas Geol. Sur., Third Ann. Rept., p. 201, 1892.

Art. XIII.—*The Plauenal Monzonose (Syenite) of the Plauenscher Grund;* by Henry S. Washington.*

Of the group of syenites, composed essentially of orthoclase and hornblende, biotite or augite, that of the Plauenscher Grund near Dresden has been the longest known and is regarded as one of the most typical,† especially of the hornblende-syenites or syenites proper. It has also been regarded as one of the few known highly potassic representatives of these rocks, or those in which the amount of potash far surpasses that of soda.‡

In the course of a study of the highly potassic volcanic rocks of Italy the close similarity of the well-known analysis by Zirkel of the Plauen syenite to those of some of the Italian lavas was noted, a similarity so great that the former might be considered as a plutonic representative of the same magma as that which furnished the lavas farther south.

As the older analysis was not altogether satisfactory because of the high summation, and its incompleteness, the oxides of iron not having been separated nor TiO_2 and P_2O_5 determined, as well as on account of its early date, a new analysis of the rock was undertaken. The material used for this was a specimen collected by myself in 1897 at one of the large quarries on the left bank of the Weisseritz south of the Gasanstalt. The results of this were quite unexpected, diverging very much from the older one in some particulars, most especially in the relations of the alkalies, as will be seen later. Some hesitation was felt about publishing the new analysis, the more so because I was informed by Professor Zirkel, to whom the analysis was shown in 1904, that the mass of syenite varied considerably from place to place, a fact which might explain the discrepancies.

It was finally decided to test this last point, and to determine the true composition of the rock, by examining specimens from different parts of the mass. As a second visit was impracticable, the object was accomplished by obtaining specimens from different sources and collected at different times. These would presumably be derived from different parts of the mass and should reveal any differences in composition should such exist, or, on the other hand, by their uniformity show that the variations were not as great as had been supposed.

* The results in this paper form part of an investigation conducted for the Carnegie Institution of Washington, the Trustees of whom I must thank for permission to publish it here.

† Cf. Zirkel, Lehrbuch, II, 1894, p. 300; Rosenbusch, Mikr. Phys., II, 1896, p. 120.

‡ Brögger, Eruptivgest. Krist. Geb., II, 1895, p. 30.

For this purpose Dr. Whitman Cross furnished me with material from a specimen (No. 234) in the Petrographic Reference Collection of the United States Geological Survey, Prof. J. F. Kemp with part of a specimen collected by himself in 1886 and now in the collection of Columbia University, and Prof. L. V. Pirsson with a piece of a specimen which had been bought by him in 1891 of Blatz in Heidelberg, and now in the collection of the Sheffield Scientific School. Each of these specimens was practically identical with mine in all respects, and the pieces, though not large, were amply sufficient to furnish representative material for analysis. It is a great pleasure to express my thanks to these friends, who have so kindly and generously aided the present investigation.

As three complete analyses would have involved the expenditure of much valuable time, it was decided instead to determine the alkalies alone in each of these specimens, since the divergencies between Zirkel's analysis and mine were most serious as regards these constituents, and it was considered that any marked variation in the igneous mass would be surely manifest in the figures for these. The results of the determinations were fully confirmatory of my first complete analysis, and indicate a remarkably uniform composition throughout the mass, at least as far as the specimens extend. Not only is this uniformity of interest as showing the true chemical composition of this well-known rock-type, but it is of some importance in a more general way by indicating the uniformity which may obtain through large igneous masses. It may be added that the alkali determinations were made in every case by the Lawrence Smith method, which experience has shown to be the most expeditious and fully as accurate as, if not more so than, the Bunsen method usually employed abroad. Since this paper has been set up the chief constituents in Cross's specimen have been determined, the results being embodied in the table of analyses.

Although the rock is well-known to all petrographers, it will be briefly described in terms of the quantitative system of classification, as an illustration of the methods of this and of the form in which the descriptions of rock-types according to this system may be stated.

I may add that it is with reluctance that I am thus compelled to point out and to correct an error of my teacher and friend, Professor Zirkel, and can but mention the fact that the analytical methods and standards of forty years ago had not attained the degree of accuracy which they have at present.

Plauenal Monzonose.

Megascopic characters.—General color, light pinkish-brown; phanerocrystalline and apparently holocrystalline, medium grain, 1 to 5^{mm}, granular equant fabric, inclining to trachytic; composed of dominant feldspar, of a brownish-pink color, mostly in tables about 5^{mm} wide and 1^{mm} thick, without twinning lamellae, which show a subparallel arrangement; subordinate hornblende in greenish black, equant anhedra, 1 to 3^{mm} in diameter; a few grains of colorless quartz and rare, small, brownish titanites.

Microscopic characters.—Holocrystalline, automorphic granular. Minerals present: alkali-feldspar, hornblende, quartz, plagioclase, magnetite, titanite, apatite.

Soda-orthoclase.—About 65 per cent; in stout subhedral plates, tabular parallel to *b* (010), Carlsbad twinning common; evidently a soda-orthoclase, with moirè appearance and microperthitic structure very common, but no microcline.

Hornblende.—About 17 per cent; in stout, subhedral prismoids or irregular anhedra, often twinned on *a* (100); color olive-green, pleochroic, c and b olive-green, a greenish yellow, c = b > a; some individuals have a narrow, irregular border of bluish green hornblende; magnetite a common inclusion, titanite and apatite less so, and orthoclase rare.

Quartz.—About 10 per cent; xenomorphic, in irregular anhedra, interstitial between the other constituents, especially the feldspar and hornblendes; occasional undulatory extinction.

Oligoclase.—(Ab_4An_1). About 3 per cent; stout subhedral tables, twinning lamellae according to the albite law very narrow and numerous.

Magnetite.—About 2 per cent; small, subhedral to anhedral grains.

Titanite.—About 2 per cent; automorphic, giving the usual lozenge sections; pale brown, slightly pleochroic.

Apatite.—About 1 per cent; automorphic, stout prisms; clear.

Chemical composition.—The chemical composition is shown in the table, the earlier analyses by Zirkel and Griffith (quoted from Brögger) being given in columns I and II, the complete analysis of my specimen in III, that of Cross's specimen in IV, followed by the alkali determinations of the other specimens, and the final average with the molecular ratios in VII and VIII.

The two older analyses are very closely alike, a fact to which Brögger has called attention. They are, however, both unsatisfactory according to modern standards, the summation of I being unwarrantedly high,* and both being incom-

* The sum would be still higher were the ferric oxide reckoned.

Analyses of syenite from the Plauenscher Grund.

	I	II	III	IV	V	VI	VII	VIII
SiO_2	59·83	60·02	62·49	58·70			60·60	1·010
Al_2O_3	16·85	16·66	16·49	17·09			16·79	·165
Fe_2O_3	...	7·21	2·36	3·17			2·77	·017
FeO	7·01	....	2·04	2·29			2·17	·031
MgO	2·61	2·51	1·87	2·41			2·14	·054
CaO	4·43	3·59	4·23	4·71			4·47	·080
Na_2O	2·44	2·41	4·38	4·38	4·34	4·49	4·40	·071
K_2O	6·57	6·50	4·65	4·35	4·33	4·93	4·57	·049
H_2O+	1·29	1·10	0·32	0·89			0·61	
H_2O-*			0·28	0·23			0·25	
CO_2	....	. ..	none	none			none	
TiO_2	....	....	0·85	0·95			0·90	·011
ZrO_2	....	....	none	....			none	
P_2O_5	....	....	0·32	0·23			0·28	·002
SO_3	. ..	....	none	....			none	
S	....	....	none	....			none	
MnO	n.d.	n.d.	n.d.	n.d.			n.d.	
BaO	....	....	0·15	....			0·15	
SrO	. ..	....	trace	....			trace	
	101·03	100·00	100·43	99·40			100·10	

Sp. Gr. 2·730

I. F. Zirkel, Pogg. Ann. cxxii, 1864, p. 622.
II. Griffith, Chem. News, xlvii, 1882, p. 170 (cf. Brögger, op. cit., p. 30).
III. Specimen of H. S. Washington.
IV. Specimen from W. Cross.
V. Specimen from L. V. Pirsson.
VI. Specimen from J. F. Kemp.
VII. Average of III, IV, V and VI.
VIII. Molecular ratios of VII.

plete, especially as regards the iron oxides, while the total of II (exactly 100·00) gives rise to some uneasiness.

They both resemble III and IV in the figures for silica, alumina, magnesia and lime, but differ much in those for the oxides of iron and the alkalies, though the total amount of these last is about the same in all. It may be noted, however, that the specimens analyzed by Zirkel and Griffith and that of Cross are evidently slightly more femic than mine. This is shown by the lower silica and higher iron oxides, magnesia and lime, as well as by the alumina when it is remembered that the Al_2O_3 of I and II include the TiO_2 and P_2O_5 of the rock.*

* The SiO_2 will also include some of the TiO_2 and possibly a little Fe_2O_3, etc., if it was not checked as to purity by evaporation with hydrofluoric and sulphuric acids. It may be noted that the unchecked silica in IV amounted to 59·45 per cent.

If the ferrous oxide of I is divided up in about the ratio shown by III, that is 3·89 Fe_2O_3 and 3·50 FeO, the norm calculated on this basis is as follows:

Quartz	7·08
Orthoclase	38·92
Albite	20·44
Anorthite	15·57
Diopside	5·19
Hypersthene	7·31
Magnetite	5·57
	100·08
Water	1·29
	101·37
Extra oxygen	0·38
	100·99

This gives as the systematic position ciminose (II.5.2.2), a rare subrang which is abundantly represented at the Italian volcanoes, but which is unknown outside of these except as the durbachite of the Schwarzwald, a rock with very abundant biotite, which is quite absent from the Plauen syenite.

The figures for the alkalies in the new analyses are remarkably constant, Na_2O varying only from 4·34 to 4·49, while the range of K_2O is slightly greater, from 4·33 to 4·93: the former being within the acceptable limits of analytical error and the latter scarcely more than this.* Silica varies within a range of 3·19 per cent, and the other constituents are somewhat higher in IV than in III, though not very much so. Taken as a whole, when we remember that silica is the most abundant constituent and the one in which a greater range of variation is to be expected, and when the different times when, and the different parts of the mass where, the specimens were collected are considered, the results of my analyses imply a remarkable uniformity in the mass of syenite. It is true that highly feldspathic, as well as highly hornblendic, schlieren occur here and there, but these are of very minor importance, besides being complementary to each other. While the close correspondence between I and II might argue a composition similar to these, their earlier date and unsatisfactory character, as well as the improbability of the systematic position to which they lead, make one feel confident that the true composition of the mass is shown by the new rather than by the older analyses, and that it is best represented by the average of these, as given in VII.

* Dittrich, Neues Jahrb., 1903, ii, p. 81; Washington, Manual Chem. Anal. Rocks, 1904, p. 24.

The norm of VII calculates out as follows:

		Norm.		Ratios.
Q	6·90	6·90	83·85	$\frac{Sal}{Fem}$ = 5·53, Class II, dosalane.
Or	27·24	76·95		
Ab	37·20			
An	12·51			$\frac{F}{Q}$ = 11·15, Order 5, germanare.
Di	6·11	9·04	13·85	$\frac{K_2O' + Na_2O'}{CaO'}$ = 2·67, Rang 2, monzonose.
Hy	2·93			
Mt	3·94	5·61		
Il	1·67			$\frac{K_2O'}{Na_2O'}$ = 0·69, Subrang 3, monzonose.
Ap	0 72	0 72		
	99·22			
Rest	1·01			
	100·23			

The average rock therefore falls in monzonose (II.5.2.3), as do both Cross's specimen and mine, and presumably the others also. It will have been seen that Zirkel's analysis places the rock in the same class, order and rang, but in the dopotassic instead of the sodipotassic subrang. As the somewhat more femic character of his specimen cannot be considered to be connected with, or to bring about, such a radical difference in the proportions of the alkalies, their total amount in I and VII being about the same, we are forced to suppose that the discrepancy is due to some analytical error, such as, possibly, a dehydration of the sodium platinichloride.

Mode.—The mode of the plauenal monzonose was determined by numerous measurements in different directions across a typical section of my specimen. The results were:

	Vol. per cent.	Wt. per cent.
Quartz	11·50	11·09
Soda-orthoclase	67·58	63·96
Oligoclase	2·90	2·79
Hornblende	14·26	16·61
Magnetite	1·38	2·61
Titanite	1·55	1·97
Apatite	0·83	0·97
	100·00	100·00

As the chemical compositions of the hornblende and of the soda-orthoclase, which may contain some lime, are unknown, it is impossible to check the measured mode satisfactorily by calculation of the mode from the chemical composition, nor conversely to calculate the chemical composition from the

measured mode as given above. It is clear, however, that the mode is decidedly abnormative, the hornblende taking up nearly all of the normative diopside and hypersthene, with a very considerable amount of the anorthite, and a little of the albite, magnetite and ilmenite. The greater part of the ilmenite is used up in forming titanite, the silica and lime needed coming from diopside and the ferrous oxide of the ilmenite taking its equivalent of silica from the normative quartz to enter the hornblende. On the other hand the estimated amounts of quartz, orthoclase and albite as given above correspond well with the figures for these in the norm calculated from III. That the mode here given is close to the truth is indicated by the specific gravity. That of my specimen was found to be 2·73 at 23°, identical with Zirkel's, while that calculated from the amounts of the several minerals shown by Rosiwal's method was 2·697, a very satisfactorily close agreement.

Name.—In a general way therefore this rock may be spoken of as hornblende grano-monzonose, but on account of its importance we may regard it as a type, to which the name of *plauenal monzonose* may be appropriately given. This name, it will be seen, implies the modal and textural characters involved in Rosenbusch's Plauen Typus of the hornblende-syenites, but more strictly defined and with a very definite indication of the chemical composition as well.

Locust, N. J., June.

Art. XIV.—*Colloidal Nuclei and Ions in Dust-free Air saturated with Alcohol Vapor;* by C. Barus.

1. *Introductory.*—In my report* on the solutional nucleus and elsewhere† I came to the conclusion that the differences in promoting condensation exhibited by positive and negative ions were more probably to be ascribed to the difference in chemical structure or composition involving a difference of size, than to the electrical differences as such. Experiments made in Wilson's apparatus by Dr. Donnan‡ with vapors of methyl and ethyl alcohol, carbon tetra-chloride, carbon-disulphide, benzol, chloro-benzol, show that the supersaturation needed to produce condensation was not necessarily greater in ionizing than in non-ionizing solvents. With similar apparatus Dr. K. Przibram§ recently examined a series of alcohols and other bodies ionized by the X-rays, obtaining among a variety of data a noteworthy result with a direct bearing on the question here at issue. It appears that whereas in the case of water-vapor the negative ions are more efficient condensation nuclei than the positive ions, the reverse holds for the alcoholic vapors. In cases of methyl, ethyl, amyl and heptyl alcohols (including some other bodies like chloroform) the positive ions invariably require less supersaturation to precipitate condensation than the negative ions of the same body.

Interesting differences are therefore manifest in the behavior of vapors, and it seemed desirable to test the nucleation of a dust-free medium of ethyl alcohol and air in comparison with the media of water-air and water-carbon-dioxide hitherto examined. The former behaves in fact as if the nuclei were throughout larger than in the latter cases. Hence the colloidal nuclei of dust-free wet air should be associated rather with the saturated vapor than with the gas.

2. *Apparatus. Method.*—The experiments were conducted with an apparatus in which the connecting pipes between the fog chamber (18 inches long, 5 in. in diameter) and the vacuum chamber (5 feet long, 1 foot in diameter) were 4 inches in diameter containing a 4-inch counterpoised, plug stop-cock. The whole connecting system was about 22 in. long, one-half of it belonging to the fog chamber. Experiments made with water-vapor, however, did not show any further marked advantage arising from the use of the large passage way specified, over the former apparatus, in which the corre-

* "Structure of the Nucleus": Smiths. Contrib., No. 1373, 1903, p. 161.
† "Ions and Nuclei": Nature, lxix, 1903, p. 103.
‡ F. G. Donnan: Phil. Mag. (6), iii, p. 305 to 310, 1902.
§ K. Przibram: Wien. Sitzungsber., cxv, pt. IIa, p. 1 to 6, 1906.

sponding tube was 2 inches in diameter. It is therefore superfluous to adduce for comparison the new data for water-vapor. The general method of work was that frequently described in connection with these investigations. With the exceptions stated all data, to be at once comparable, must be obtained with a given pair of fog and vacuum chambers.

3. *Properties of alcohol fog.*—While the experiments of my last paper with the medium of water-vapor and carbon-dioxide gas showed unusually high values of the exhaustions needed to produce coronal condensation, the case of alcohol air shows correspondingly low values of exhaustion, as compared with those for water-air. The number of colloidal nuclei entrapped by alcohol vapor are about 3·5 times larger than is the case for water-vapor under like conditions. Hence the coronas for alcohol are exceedingly dense by contrast. They are also much less regular in color and, particularly at high exhaustions, become fog-like. The phenomenon is coarsened and measurement less satisfactory.

As the alcohol fog particles are larger in size, they subside more rapidly at the same exhaustion than water particles: but the occurrences are in the former case far from simple. While in the earlier experiments the corona (if not too large) remained nearly the same throughout the slow subsidence of water particles, the coronas for water and for alcohol particles in the present work decreased one-half or more in size during this period. In other words, the fog particles now experience very rapid growth* during subsidence, from which it follows many of them must evaporate to compensate in part for the eightfold or more enlargement in bulk of the survivers, or further vapor may condense. The same fact may account in alcohol, where the phenomenon is more rapid, for the blurred coronas; for the true initial corona, being very evanescent, is probably not seen. Conformably with this view, it is impossible to exceed large white reddish forms in the present apparatus and to reach the high greens observed with water-vapor.

4. *Number of particles.*—In order to determine the number† of particles corresponding to a given corona, it is first necessary to compute the amount of alcohol precipitated per cubic centimeter of the exhausted vessel, by the sudden cooling incident upon exhaustion. This may be done by a straightforward approximation‡ with results shown in the following table, where t_1 is the initial temperature of the saturated air within the fog chamber, t_2 the temperature after sudden exhaustion and before condensation, and t the temperature

* The precise reasons for this growth may be of some importance in relation to rain.

† C. T. R. Wilson: Phil. Trans., London, vol. clxxxix, 1897, p. 300.

‡ The size of fog particles in terms of the apertures of the coronas is found as shown in my earlier papers (Smithson. Contrib., No. 1373, Chap. VIII).

after the precipitation of the m grams of alcoholic fog per cubic centimeter. The drop in pressure* is δp from $p = 76^{cm}$ at 20° C. The data of the last columns will be presently explained.

δp cm	t_1 °C	t_2 °C	t °C	$m \times 10^{-6}$ grams	p_r/p_∞	$r \times 10^7$ cm
10	20°	+ 3·2°	+14·8	$10{\cdot}0^g$	2·42	1·44
20	20	−15·3	+10·2	18·3	6·21	·75
30	20	−36·1	+ 3·2	22·8	21·4	·48

These may be compared with the case of water vapor.

85	20°	+ 5·8°	+14·7°	$2{\cdot}6^g$	2·17	1·65
17	20	− 9·6	+ 8·8	4·6	5·68	·77
22	20	−18·9	+ 4·6	5·5	11·1	·58
30	20	−36·1	− 3·5	6·4	69·7	·35

We may infer from the table that in a perfect apparatus, water fog particles would reach freezing (0° C.) at $\delta p = 24^{cm}$ and alcohol fog particles at $\delta p = 34{\cdot}5^{cm}$. Moreover for the same corona there must be on the average about 3·5 times more particles in the alcoholic fog than in the water-fog, which accounts for the opaqueness of the former.

For the reasons adduced it is not worth while to express the results otherwise than in round numbers, for the data involved are inevitably crude. The assumption of the law of adiabatic cooling as far as −36° C. is questionable in view of the admixture saturated vapor: but as the densities of vapor are for alcohol about 8 per cent that of air and for water vapor about 7 per cent, this approximation in a rarified atmosphere, as well as the use of Boyle's law for a wet gas, is probably admissible. It is different, however, with the latent heat of the vapor, which is required at the low temperatures, but is known (as a rule) only at temperatures near the boiling point. From this and similar points of view, measurements of latent heat for the more common vapors at very low temperatures would be desirable.

Finally the point at which the drop in pressure ceases to be efficient, because of the increasingly rapid inward radiation of heat from the vessel, is the most serious of the outstanding errors. I have endeavored to diminish it compatibly with the desideratum of a large and easily adjusted fog chamber, by successively increasing the bore of the exhaust pipes and stopcocks; and this plan has been in a large measure successful. The extent to which the error is present, as the drop in pressure increases more and more, is nevertheless left unanswered.

* The value of δp here referred to is the experimental value observed under isothermal conditions at the fog chamber. The value computed from the dimensions of fog and vacuum chambers is $\delta p \times {\cdot}775$, as will be shown elsewhere.

If the upper inflection of the distribution curve (fig. 2) is a criterion, i. e., if adiabatic cooling ceases with the occurrence of identical terminal coronas for successively increasing exhaustions, the fog chamber with water-air is efficient to about $\delta p = 31$ or 32^{cm}, with water and carbon-dioxide to about $\delta p = 37^{cm}$, with alcohol and air to about $\delta p = 20^{cm}$. In the former case the vapor would be cooled from 20° to about −10° C. even after condensation: in the latter case to about +10°. On general principles and in view of the low temperatures of the water particles, it would seem probable that the efficiency of the fog chamber must vanish gradually. But the appearance of the curves is such, as if the action were unimpaired up to a given terminal drop in pressure.

In every case the fog particles with the surrounding medium of vapor soon reach the temperature of the air again, so that additional moisture must arrive from somewhere. It has been instanced above that the marked constancy of the water-coronas during this period in the work done heretofore gave no evidence of the evaporation; while the present water and alcohol coronas decrease one-half in aperture, i. e., the preponderating fog particles actually grow, because the exhaustion is slowly but steadily incremented when the stop-cock is not quite tight, the fog particles acting like very large nuclei. Even if this is compatible with the evaporation of the smaller particles, there is again no evidence for it. Much of the moisture must therefore come from the wet cloth and the water within the vessel, which are not cooled by the expansion.

5. *Size of the nuclei.*—Here it may be worth while to inquire into the reason why the precipitation in alcohol is apparently so much easier; or what is the same thing, into the estimated size of the nucleus on which precipitation takes place in these several cases. The Kelvin equation as modified by Helmholtz* may be used† for this purpose (as was done by the latter and by Wilson‡ in the form $p_r/p_\infty = \epsilon^{2T/Rs\theta r}$ where p_r and p_∞ are the vapor pressures at the convex areas of radius r and radius infinity respectively, T the surface tension of the liquid of density s, R the gas constant of its vapor at the absolute temperature θ. Since p_r is the adiabatically reduced vapor pressure (without condensation) in the volume expansion due to the drop of pressure δp, and p_∞, the normal vapor pressure at the same temperature $\theta = 273° + t_2$ in Table I, r follows from the equation. The values of $S = p_r/p_\infty$ and r so found are both given in Table I, and have been constructed in

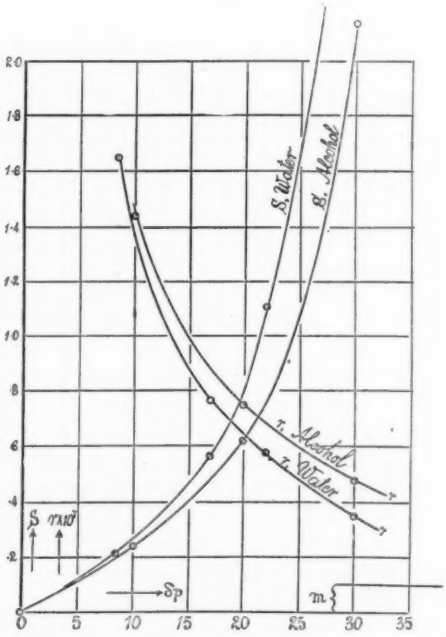
* Helmholtz: Wied. Ann., xxvii, p. 524, 1886.

† Similar estimates of my own are given in Bull. U. S. Weather Bureau, No. 12, 1895, p. 48.

‡ C. T. R. Wilson: Phil. Trans., vol. clxxxix, 1897, p. 305.

the chart, figure 1, where their relation to the usual order of molecular size (m in the figure) is also indicated. Clearly these values of r, the radius of the nuclei differing so little from molecular radii (say 10^{-8} cm), can only indicate an order of values; for apart from the difficulties above enumerated in computing θ, r depends on surface tension T, which has no meaning for molecular dimensions. Granting this, it is none

1



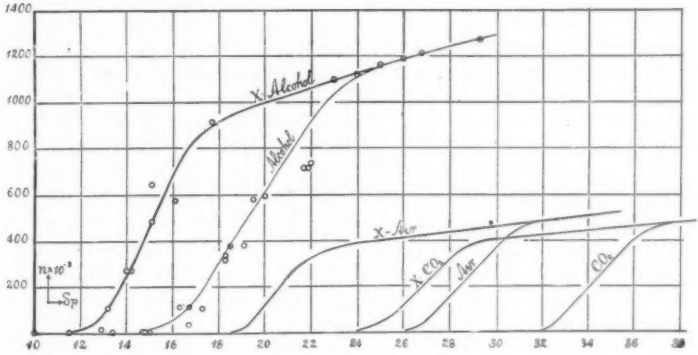
the less remarkable that the values of r obtained should be so nearly alike for water and alcohol, where different constants (T, R, s, etc.) occur throughout; in other words, that at a given temperature a given drop of pressure will condense both vapors on nuclei of about the same size.

In so far as these estimates are admissible, it follows that the alcohol air nucleus is larger than the water air nucleus; in the former case coronal condensation begins at about $\delta p = 15^{cm}$, where $r = 10^{-7}$, while in water vapor it begins at $\delta p = 26^{cm}$, where $r = 4 \times 10^{-8}$ about, less than half as large. These relations once established are retained through all successions of nuclei, as the following data for alcohol vapor in compari-

son with water vapor show. It is a little difficult to understand why the ionized nuclei in alcohol vapor should, like the colloidal nuclei, be larger than the corresponding cases for water vapor, unless the ions are aggregated colloidal nuclei, a point of view tentatively advanced elsewhere.*

6. *Data for alcohol vapor.*—The behavior of alcohol vapor is shown in the usual way in the following chart, fig. 2, where δp is the sudden fall in pressure from normal atmospheric pressure, producing the corona of the angular diameter

2



s / 30, when the eye and the source of light are at distances 40 and 250 cm on the opposed sides of the fog chamber. The nucleation n deduced from s is computed in the way given above, § 4, and indicates the number of nuclei in the *exhausted* fog chamber. It is assumed therefore that the nuclei are reproduced more quickly than they can be withdrawn by the exhaustion. Measurement of s is not very satisfactory, as the coronas are blurred and accompanied by dense fogs and change rapidly on subsidence. The effect of X-radiation leads to the same terminal corona which appears for the non-energized vapor.

The results as exhibited in fig. 2 are seen in connection with earlier results for media of water-air and water-carbon-dioxide, the same condensation apparatus and method underlying all experiments. One may notice at once that in the cases CO_2-water and air-water, both for the non-energized and for the energized state, the observed data would be obtained by shifting the air-water diagram as a whole to the right, as if the cooling in case of CO_2-water vapor were less efficient.† The

* This Journal, xx, 1905, p. 453; Phys. Review, xxii, 1906, p. 109.
† Phys. Review, April, p. 252, August, 1906.

graphs are of the same kind, nearly parallel, and all of them (energized or not) again terminate in the same asymptote or large green-blue-purple corona.

The alcohol curves differ from the water curves chiefly in three respects: (1) though the graphs both for the non-energized and energized states terminate in a common asymptote, this is not the green-blue-purple corona, but the white-yellow corona lying slightly below it; (2) the curves as a whole lie with a somewhat larger slope in a region of much lower exhaustions (δp); (3) the number of nuclei caught in alcohol vapor is relatively very large. The second and third observations have already been discussed. The first deserves especial consideration. The question occurs at once why both the energized and the non-energized curves should be limited by the same final corona, irrespective of the size of the nuclei, and why this should be lower for alcohol than for water. For the ionized state one might infer that the total number of ions has been precipitated, as is actually the case at low ionization; but if under strong ionization this were true for alcohol vapor, it could not be true for water vapor, where the number of ions caught is less than one-half the number in alcohol. In general it is improbable that the terminal corona for ions should in such a case be the same as the terminal corona for colloidal nuclei.

The explanation which seems plausible to me is this; each nucleus must drain the air of its supersaturated moisture within a certain radius large as compared with the size of the nucleus and increasing in the lapse of time.

A limit of the phenomenon will be reached when for an indefinite number of graded nuclei the enveloping spheres free from supersaturation form a system in contact. In case of water vapor the distance between centers would be $\cdot 014^{cm}$; in case of alcohol $\cdot 010^{cm}$, distances which are both enormous as compared with the estimated size of nuclei (r), Table I. At all events, when the limiting *number* of nuclei has been captured, the apparatus is powerless to produce condensation on a greater number of nuclei, be they relatively large as the ions or small as the colloidal nuclei, however many other (inefficient) nuclei may be present.

Brown University, Providence, R. I.

ART. XV.—*The Russian Carboniferous and Permian compared with those of India and America. A Review and Discussion;* by CHARLES SCHUCHERT.

[Continued from p. 46.]

PART III. THE WORK OF DIENER.

1. *The Permocarboniferous Fauna of Chitichun No. I.* Mem. Geol. Surv. India, ser. xv, Himálayan Fossils, vol. i, pt. 3, 1897, pp. 1–105, pls. i–xiii.
2. *The Permian Fossils of the Productus Shales of Kumaon and Gurhwal.* Ibid., pt. 4, 1897, pp. 1–54, pls. i–v.
3. *Permian Fossils of the Central Himálayas.* Ibid., pt. 5, 1903, pp. 1–204, pls. i–x.

In the central Himalayas at the limestone crag of Chitichun No. 1, at an elevation of 17,700 feet, Griesbach, Middlemiss, and Diener, in the year 1892, discovered a lot of fossils described in the work cited above (1). The stratigraphical results of this collection are described by Diener on pp. 85–105, from which are taken the following extracts:—

"Karpinsky and Tschernyschew, two authors to whom the most detailed studies of the Artinskian fauna are due, strongly advocate the distinction of the permocarboniferous from carboniferous and permian systems, and are decidedly averse to uniting it with either the one or the other. Tschernyschew especially strongly combats the view of the majority of geologists who proposed to unite the permocarboniferous with the permian, as a lower division of the system. According to him a separation of the permocarboniferous from the permian system is demanded by the general aspect of the fauna, in which the carboniferous types greatly predominate, chiefly among the brachiopods. If it ought to be united either with the carboniferous or permian system, in spite of its distinctly intermediate position, it must necessarily be placed in the former, on the strength both of the carboniferous character of its fauna and of historical priority, since the Artinskian sandstone had been correlated with the carboniferous millstone-grit of Western Europe by Sir Roderick Murchison, who first introduced the name permian.

"Against the first argument the objection may be raised that notwithstanding the prevalence of carboniferous types in the Artinskian fauna, the latter 'marks a very important moment in the history of development of organic remains, namely, the first appearance of true ammonites with complicated sutures.' Nor is the large percentage of carboniferous types in the Artinskian fauna an astonishing fact, in view of the absence of any break in the sequence of marine beds from the upper carboniferous to the true permian strata. Even in beds, which must be placed very high in the permian system, in the upper Productus limestones of the Salt Range and in the Oto-

ceras beds of Julfa, the fauna contains a proportionately large number of carboniferous forms. It is to the faunas of these deposits, the normal representatives of the pelagic permian [by this the author means a *normal* marine fauna], not to the local fauna of the Zechstein, that the permocarboniferous fauna must be compared, if we want to get a clear idea of its relationship to those of the upper carboniferous and permian. Bearing in mind the gradual passage from an upper carboniferous to a permian fauna through the intermediate group of rocks, the question to be answered is, which consideration is of the greater importance in defining the boundary between the two systems, the appearance of a new group of cephalopods, which become of an unparalleled stratigraphical value in mesozoic times, or the presence of a belated fauna, composed of forms which are generally not well adapted for the characterization of narrowly limited horizons.

"The majority of geologists have decided in favour of the first alternative. Gümbel, Krassnopolssky, Kayser, Waagen, Credner, Munier-Chalmas and A. de Lapparent, Frech—to enumerate only a small number among them,—are unanimous in regarding the permocarboniferous as the lowest division of the permian system" (pp. 87–88).

"In the Mediterranean region three different rock groups have yielded fossil remains of this pelagic development of the permian epoch. These rock groups are the Fusulina limestones of the valley of Sosio in Sicily, the Bellerophon limestone of South-eastern Tyrol and Friaul, and the Otoceras beds of Julfa in Armenia. All of them are of a rather isolated occurrence and, as far as one may judge from their faunas, of different age.

"The lowest position is apparently held by the Fusulina limestone of Sicily. Its cephalopod fauna seems to be more nearly related to the Artinskian one than to those of the Jabi beds of the Salt Range or of the Otoceras beds of Julfa. Ammonites with ceratitic sutures are yet absent. According to Karpinsky's statement, one species of *Medlicottia* is identical with an Artinskian form; ten more species are very nearly allied. On the other hand, Karpinsky and Waagen noticed the first appearance of *Waagenoceras* and *Hyattoceras* in Sicily, two genera which show a much more complicated sutural line than any of the Artinskian *Ammonea*. Waagen consequently places the Fusulina limestone of Sicily on a higher level than the permo-carboniferous stage, but on slightly lower level than the Jabi beds of the upper Productus limestone. . . .

"The Otoceras beds of Julfa with their strongly marked triassic affinities must certainly be higher in the upper palæozoic series than the Fusulina limestone at Sosio. They cannot be much different in age from the Otoceras beds of the Him-

alayas, although the latter certainly hold a somewhat higher stratigraphical position, and they may consequently be placed on a level with the upper Productus limestone or with the Chidru group of the Salt Range.

"The youngest of the three rock groups is probably the Bellerophon limestone of South-eastern Tyrol. Its fauna is a very peculiar one, species identical with those known outside this rock group being almost completely absent. The predominance of palæozoic types induced Stache to fix the homotaxis of these beds as upper permian, whereas Gümbel supposed them to be of lowest triassic age. . . .

"In none of these three permian rock groups of the Mediterranean region is a normal sequence of marine beds exposed, with the possible exception of the Bellerophon limestone of the Carnian Alps, which, however, is underlaid by an enormous mass of unfossiliferous limestones and dolomites. Their correlation must consequently be based on palæontological evidence alone" (pp. 90–91).

Recently, Schellwien and Kossmat (Monatsber. No. 9, Deutsch. Geol. Gesellsch., 1905, pp. 357–9) found in the Bellerophon limestone (usually regarded as the topmost Permian of the Alps) of Krain, west of the Laibach plain, a fauna consisting in the main of brachiopods, corals, and Foraminifera. As yet the fossils are not worked out of the matrix, but the following species are determined: *Richtofenia* aff. *lawrenciana*, *Productus indicus*, *P. abichi*, *Marginifera ovalis*, and *Lonsdaleia indica*. In regard to these fossils Schellwien concludes as follows:—

"The finding of this fauna dispels all doubt as to the Permian age of the Bellerophon limestone. The value of this discovery in fixing the time position of this limestone, however, is overshadowed by the greater one,—that of fixing the chronologic position of the Productus limestone [of India], the correlations of which, as is known, are still at variance. The fossil-bearing beds of the Bellerophon limestone are everywhere in close association with the lower Werfen beds [Triassic]: in southern Tyrol the boundary between the Werfen deposits and the Bellerophon limestone is difficult to establish. At Krain the fossiliferous zones of the Bellerophon limestone are also separated, but by a thin dolomite series from the Trias. These upper dolomites introduce micaceous layers and gradually pass into the Werfen slates, with their well-known bivalve fauna. The Bellerophon limestone, therefore, can represent only the highest zone of the Permian, and for the Productus limestone the same view may also be affirmed. Worthy of note is the fact that of this fauna of the Bellerophon limestone, it is also not only those of the higher zones of the Indian Productus limestone but likewise forms of the

lower horizons. Should the detailed examination show that the fossils of the various horizons of the Productus limestone are also found associated in the thin fossiliferous zone of the Bellerophon limestone of Krain, the conclusion will be unavoidable that the various zones of the Productus limestone are of Upper Permian age."

In the second paper cited above, treating of the fauna of the Productus shales, Diener states the following:—

"The only decisive evidence for a permian age of the Productus shales is however based on their stratigraphical relations to the triassic beds of the mesozoic belt of the Central Himalayas, not on their fossil remains. One of the chief results of Griesbach's geological survey of the Bhot Mahals of Kumaon and Gurhwal is the proof of an unconformity, existing at the base of the Productus shales, which locally overlap successive strata of carboniferous age. With this unconformity another uninterrupted sequence begins, with conformable bedding throughout, which ranges from the Productus shales to the topmost beds of the triassic system. So intimate is the stratigraphical connection between the Productus shales and the following Otoceras beds of lowest triassic age, that a sharp boundary cannot be drawn between them" (pp. 53–54).

In the third publication above cited, Diener reviews his former work on the fossils of Chitichun No. 1, owing to larger and more significant collections subsequently made by Walker. These collections have not altered Diener's correlations with the Salt Range, but they have, when interpreted in the light of Noetling's publications, caused him to depart strongly from the nearly unanimous views of European stratigraphers and to agree in the main with the intercontinental correlation of Noetling. Great weight should be attached to the correlation of these two paleontologists, for they have collected the fossils of the Permian in India and studied them in the laboratory. Diener's conclusions are as follows:—

"So far there is no reason for any change in my correlation of the Chitichun fauna with Indian faunæ of permian age, as proposed by myself in 1897. I am, however, bound to confess that the affinities of the Chitichun fauna to those of Europe have not been correctly interpreted, and that my examination of Walker's materials is apt to lead in this respect to results remarkably different to those deduced in my first memoir.

"In that memoir [here numbered 1] the conclusions at which I arrived with regard to the stratigraphical position of the Chitichun fauna were summed up as follows:—

"'The Chitichun limestone is approximately homotaxial with the upper division of the middle Productus limestone (Virgal and Kalabagh beds) in the Salt Range. It probably corresponds in age to the permo-carboniferous horizon (Artin-

skian stage) in Russia, but the description of the Brachiopoda from the Fusulina limestone of Sicily must be awaited before it is possible to decide whether it does not hold a slightly higher position in the stratigraphical sequence than the Artinskian deposits.'"

"This mistake of correlation is the legitimate outcome of an erroneous interpretation of the stratigraphical position of the Salt Range Productus limestone. The supposition 'that the entire Productus limestone forms a series, which cannot be separated from the carboniferous system and that the Fusulina-bearing Amb beds certainly belong to the latter,' was not my fault. I followed the majority of European palæontologists in this, and my error was due to the ignorance of the leading palæontologists as to the right means of correlating rock-equivalents of anthracolithic age in Europe and in India.

"Waagen believed the Productus limestone to be permian, but to represent the entire permian system. He consequently correlated the lower Productus limestone and the Katta beds of the middle Productus limestone with the Artinskian stage of Russia, considering them as permo-carboniferous. The palæontological investigations of Nikitin, Frech and Tschernyschew raised doubt as to the validity of this correlation. The affinity of the fauna of the lower Productus limestone to those of the upper carboniferous rocks of Russia and the Ural Mountains and of the Carnian Fusulina limestone of the Eastern Alps induced Rothpletz (Palæontographica, vol. xxxix, p. 63), Frech (Die Karnischen Alpen, p. 372), Oldham (Manual of the Geology of India, 2nd edn., p. 125), and Suess (Denkschr. kais. Akad. d. Wissensch. Wien, math. nat. Cl., vol. lxi, p. 439) to correlate the lower Productus limestone with the upper carboniferous rather than with permo-carboniferous beds. In the meantime Tschernyschew called attention to the strongly marked affinities of the faunæ of the middle Productus limestone and the Artinskian stage. On palæontological grounds he tried to prove that the entire middle Productus limestone ought to be synchronised with the Artinskian strata of Russia.

"In admitting this homotaxis I merely followed the almost unanimous judgment of European geologists. The equivalence of the Chitichun limestone to the Virgal and Kalabagh beds in the Salt Range having been clearly demonstrated, the necessity of correlating it with the Artinskian stage of Russia was obvious.

"I have been convinced of the incorrectness of this correlation both by the recent reports of Dr. Noetling on the classification of the Productus limestone and of the Ceratite formation in the Salt Range, and by my own examination of the fossil materials collected by Walker" (pp. 53–54).

"I do not, however, believe that the Chitichun limestone

should be placed on a level with the Fusulina limestone of Sicily. So far as it is possible to judge from its Cephalopoda, the Chitichun fauna appears to be geologically younger. Ammonites with ceratitic sutures such as *Xenaspis carbonaria*, or with complicated sutures, such as *Cyclolobus Walkeri*, speak clearly in favour of a homotaxis of the Chitichun limestone with true upper permian strata of Europe" (p. 57).

"The evidence afforded by the two species of ammonites which were collected by Walker, together with Noetling's discovery of the true horizon of *Xenaspis carbonaria* in the Productus limestone of the Salt Range, is sufficiently strong to affect my view as to the correlation of the Chitichun limestone with permian beds of other countries, and obliges me to consider the latter as about homotaxial with the permian rocks of Timor and as slightly younger than the Sosio limestone of Sicily. I am therefore compelled to admit the correctness of Noetling's statement that there is at present no proof of the existence of a fauna of Artinskian age in the Himalayas" (p. 58).

Diener then takes up the "Correlation of the Anthracolithic System in Spiti with the Carboniferous and Permian Systems in Europe and India."

"Wherever in Spiti a complete series of the anthracolithic system is developed and well exposed, *two groups* can be recognised and distinguished, as has been stated by Hayden. Both groups are separated by a great *unconformity*, and differ remarkably in their faunistic character and in their lithological features.

"The group above the great unconformity, which corresponds to the Productus shales of the Niti area, is much better known than the lower division, because richer collections of fossils have been examined" (p. 193).

"The fossils to which the greatest stratigraphical importance must be attributed are the ammonites of the two genera *Cyclolobus* and *Xenaspis*. The presence of a species which is most nearly allied if not actually identical with *Cyclolobus Oldhami*, Waag., and the frequent occurrence of representatives of the genus *Cyclolobus*, speak very strongly in favour of a correlation with the upper Productus limestone of the Salt Range. In the Salt Range *Xenaspis carbonaria* is, according to Noetling, restricted to one single horizon only, namely, to the top beds of the middle Productus limestone" (p. 195).

"As faunistic elements of special interest in the Kuling shales of Spiti, *Grypoceras* sp. ind., *Myophoriopis Kraffti* and *Spirigera* cf. *protea* var. *alata* may be quoted. The first and second are remarkable for their decidedly triassic affinities, the third belongs to a group of forms which has hitherto been recorded only from the permian rocks of Djulfa" (p. 196).

"Our knowledge is much more scanty with regard to the lower series of the anthracolithic system in Spiti, which is situated below the great unconformity.

"According to Hayden, the total thickness of this series is not less than 5,000 feet in the section above Lio on the Lipak river, where the sequence of the beds is most complete. Two fossiliferous horizons only have been discovered in this mighty sequence" (p. 198).

The fossils of the "upper horizon," or the Fenestella beds, are not stratigraphically significant, and the little there, considered in connection with the fauna of the lower beds, is rather in favor of regarding it as of Lower Carboniferous age.

In the lower flaggy limestone horizon (8a of Griesbach) the fossils are "unfortunately, scarce, generally ill preserved, and of a rather indifferent character." Diener thinks the age of the fossils is "more in favor of an upper carboniferous age," but his evidence is completely shattered in the appendix to his work, in a "Note on *Spirifer Curzoni*, Diener. By H. H. Hayden, Geological Survey of India." This author shows in the most convincing manner that the original generic identification of Diener was correct and that the species is to be called *Syringothyris curzoni*. A careful examination of Mr. Hayden's note, his illustrations, and those of Diener, will convince any American student of the Brachiopoda that the form in its general expression and size is to be compared with American forms low down in the Lower Carboniferous series. In further support of this lower Lower Carboniferous suggestion may be cited *Spirifer* cf. *strangwaysi* comparable to American *S. forbesi*.

Therefore it would seem that the entire 5,000 feet of material beneath the great unconformity may be Lower Carboniferous. The lower portion is certainly so and apparently nearly basal Lower Carboniferous.

Part IV. The Work of Girty in the Trans-Pecos Region of Texas.

1. *The Upper Permian in Western Texas.* By George H. Girty. This Journal, Nov., 1902, pp. 363–368.
2. *Report of a Reconnaissance in Trans-Pecos Texas.* By G. B Richardson. Univ. Texas Mineral Surv., Bull. 9, 1904, pp. 32–45. Fossils determined by G. H. Girty.
3. *The Relations of some Carboniferous Faunas.* By George H. Girty. Proc. Washington Acad. Sci., vii, 1905, pp. 1–25.

The work of this paleontologist on the Carboniferous and Permian of southwestern Texas is best summarized in tabular form, the data being taken from his three papers on the subject.

Beginning with the highest beds, the facts are as follows:–

Guadalupian.

Capitan Limestone.

Above the Guadalupian or Capitan limestone there seemingly follows an unconformity of considerable extent. Then follow beds of gypsum, a white magnesian limestone, and a sandstone the age of which is unknown but apparently is best referred to the Triassic.

A massive white limestone. At least 1800 feet thick. Top not seen.

From the middle of this limestone comes a fauna, nearly all of which is new.

Fusulina elongata, *Acanthocladia*, *Goniocladia*, *Geyerella*, *Orthothetina*, *Productus popei*, *P. mexicanus*, *Spirifer mexicanus*, *Squamularia* (?) *guadalupensis*, *Spiriferina billingsi*, *Hustedia meekana*, *Pugnax swallowiana*, *Rhynchonella* (?) *indentata*, *Leptodus* (= *Lyttonia*), *Richthofenia permiana*, *Myoconcha*, etc.

Delaware Mountain Formation.

Essentially sandstone and limestone. Maximum thickness about 2300 feet.

At the base, in black limestone, occur: *Enteletes*, *Meekella*, *Hustedia meekana*, *Pugnax*, *Richthofenia permiana*, *Foordiceras*, and other ammonoids.

Higher up in the sandstone occur: *Fusulina elongata*, *Productus* cf. *subhorridus*, *Leptodus* (= *Lyttonia*), *Richthofenia permiana*, *Laevidentalium canna*, etc.

In the limestone occur: *Fusulina elongata*, Bryozoa of Mesozoic type, *Chonetes permianus*, *Hustedia meekana*, *Rhynchonella bisulcata*, *Leptodus* (= *Lyttonia*), *Richthofenia permiana*, and ammonites.

Hueconian or Pennsylvanian.

Mainly massive limestone with local shales and sandstones. Maximum thickness at least 5000 feet, more than 2000 feet of which are limestone.

Near the base occur: *Triticites*, *Productus cora*, *Marginifera* cf. *wabashensis*, *Reticularia perplexa*, *Spirifer rockymontanus*, etc.

Near the top occur (those marked "1" are Ural and "2" Indian types): *Fusulina*, *Enteletes* cf. *hemiplicatus*, 1 *Productus* cf. *inflatus*, 1 *P.* cf. *pustulatus*, 1 *P.* cf. *longus*, 1 *P.* cf. *irginæ*, *Marginifera* cf. *wabashensis*, 1, 2 *Spirifer* cf. *marcoui*, *Seminula mexicana*, 1 *Camarophoria* cf. *mutabilis*, 1, 2 *C.* cf. *crumena*, 2 *Dielasma* cf. *truncatum*, 1 *Omphalotrochus obtusispira*.

Regarding these formations and their correlation, Girty writes:–

"The Carboniferous faunas of the Trans-Pecos region, especially the upper ones, differ widely from those of the Central and Eastern States. The fauna of the Hueco formation, however, is found with some modifications over most of the area west of the Rocky Mountains; but the remarkable group of fossils occurring in the Capitan limestone is only known in the Guadalupe Mountains. The fauna of the Capitan limestone differs to a marked degree from that of the Hueco formation, and was assigned to the Permian epoch both by Shumard, its original discoverer, and by Girty. The fact that the faunas of the Hueco formation in some respects strikingly resemble those of the *Spirifer marcoui* zone, the *Omphalotrochus whitneyi* zone, the *Productus cora* zone and the *Schwagerina* zone of the Carboniferous section of eastern Russia, which immediately underlie the typical Permian, seems to support the views of these authors. On the other hand, there are some matters of difference between the Russian faunas and those of the Hueco formation, part of which are points of agreement with the Capitan fauna. Thus, the Russian faunas, even the highest (that of the Schwagerina zone), seem, aside from containing aspects not found in either, to combine features of both the Hueconian and the Capitan faunas, features, moreover, which these formations do not possess in common.

"The American beds can hardly be looked on as being a mere expansion of the Russian series, since the Hueco, Delaware Mountain and Capitan formations combined have a thickness much exceeding 5000 feet, while the four zones recognized by Tschernyschew are considerably less than 1000 feet thick. In view, therefore, of the preponderating resemblance shown in the Hueco faunas and the differences in that of the Capitan limestone, the latter is retained under the title of Permian, and with it, provisionally, the Delaware Mountain formation" (2, pp. 42–43).

The latest paper by this same author makes the following important statement regarding the Permian question, and gives his views concerning the equivalence of the formations in the various American regions:–

"The opinion has been expressed that the Pennsylvanian faunas of eastern and western United States may belong in different provinces, and that they are probably to some extent equivalent. The belief is tentatively held that the highest of our Western horizons are considerably younger than the highest known invertebrate horizons of the East, those of the Kansas section, for instance, which are characteristic of the so-called Permian of the Mississippi Valley. In spite of the able pen

which have traversed this subject, the correlation of these beds is still one of the unsettled problems of the American Carboniferous. If the Capitan fauna is Permian, then certainly that of Kansas is not, for 2 Carboniferous faunas could scarcely have less in common. While it is possible that the so-called Kansas Permian is a provincial phase of the Guadalupian, this is yet to be demonstrated, and it is questionable whether for 2 faunas so essentially unlike, even if proved to have been contemporaneous, the same name could with propriety be used. On the assumption that the Kansas beds are Permian, so closely are they connected, faunally and stratigraphically, with those below, the term Permian must be reduced to denominate a difference not much greater than that between the Burlington and Keokuk, or else most of the Kansas section must be placed in the Permian, a disposition against which there is much evidence. It seems probable that the Kansas Permian represents a faunal development in a distinct province from that of the West, the Western faunas being co-provincial with the typical Permian sea. The equivalence of the Kansas Permian is not to be determined upon the basis of a community of a few slightly differentiated long-lived types, but must be worked out by a consideration of the fauna as a whole and the facies which it receives from the presence of equivalent but probably not equal species.

"The Guadalupian faunas are not only widely different from those of Pennsylvanian age in the Mississippi Valley, but they appear to have a distinctly younger facies, biologically considered. So far as the significance of the somewhat hastily reviewed evidence has been grasped, it seems to assign the Kansas faunas to about the horizon of the Hueco formation, placing the entire Guadalupian series, or at all events the Capitan, as a younger evolution, whether the 2 faunas were developed in distinct provinces or in the same" (3, pp. 25–26).

The late Paleozoic formations have great development in Alaska, but as yet the faunas have only been partially studied. Schuchert's (Prof. Paper 41, U. S. Geol. Survey, 1905, pp. 42–45) conclusions regarding these fossils are as follows:—

"In looking over the collection listed in the large table not submitted in this report, the first impression made is its strangeness when compared with other American late Paleozoic faunas, excepting that of northern California as yet unpublished. Nearly every species is new, certainly new for North America so far as the published record goes. The developmental aspect is clearly late Paleozoic, and yet there is not present a single diagnostic upper Carboniferous or Permian species of the Mississippi Valley. Further, we miss of the brachiopods of the last-named basin the ever-present

Rhipidomella, *Enteletes*, *Derbya*, *Meekella*, *Seminula*, and *Hustedia*. On the other hand, this arctic fauna predominates in *Productus* and *Spirifer*. Of the former genus the species are nearly all strangers to American paleontologists, since the bilobed or deeply sinused and the abundantly spinose forms are the common ones. The *Spirifers* also are strange in that hardly any have the plications strongly bundled as in *S. cameratus*, while such little known groups as that represented by *S. arcticus* and *S. supramosquensis* (also recalling *S. neglectus* of the Lower Carboniferous) predominate.

"Ten or more species of Bryozoa are present, of *Fenestella*, *Pinnatopora*, *Goniocladia*, and *Rhombopora*. None, however, can be specifically identified and those of the genus *Rhombopora* are of a type—stout branches from $\frac{1}{4}$ to $\frac{3}{8}$ inch in diameter—unknown in the Mississippi basin. This is also true of *Goniocladia*. Pelecypoda are all small and rare (5 species), and the Gasteropoda (3 species, 4 specimens) almost absent. Not a trace of a cephalopod is present, and this is all the more strange since the Indian Permian has 14 forms of nautiloids and 7 of ammonoids. Nor is there a trace of a trilobite, while the corals are represented by one or two species of cyathophylloids.

"The work of the United States Geological Survey in California and Alaska is establishing two facts of great value in general geology, namely, that on the west coast of North America there is (1) a great thickness and grand sequence of Carboniferous and Permian strata [between 6000–7000 feet of Permian in Copper River region of Alaska]; (2) that these have faunæ of the Pacific type and not of that of the Mississippi basin" (p. 44).

Conclusions.

As the great Russian geologist has stated in his introduction that he will be the first to greet friendly criticism "with pleasure," the present reviewer takes the opportunity of concluding this long review with the following friendly remarks:—

1. The foregoing review of the recent work of four excellent investigators in the correlation of Carboniferous and Permian strata and faunas shows clearly that a final interpretation of the sequence of events closing the Paleozoic is still far from attainment. Further, that while harmony exists regarding the basal zone of the Carboniferous (Upper Carboniferous of most writers), there is as yet no agreement as to the upper limits of this system of rocks and hardly any concerning the delimitation and sequence of the Permian. As has been seen, there is little or no difference of opinion in regard to the sequence of

events in a given area; but when it comes to correlating these local sections with those of other continents, there is great diversity of interpretation relative to the values to be placed on the varying faunas. This lack of harmony is primarily due to the absence of a continuous faunal sequence in any one region. Further, some paleontologists draw their species finely, others broadly; and as all the Carboniferous faunas have a general facies in common, far more decided than that of any other Paleozoic system, and finally, as many of the groups of brachiopods, the prevailing fossils of the Carboniferous and Permian, have lost their power for rapid or marked progressive evolution, with a decided tendency toward degeneracy, the possibility for wide differences of opinion regarding sequential change in faunas is apparent. Then, too, the centers of radial dispersion of the faunas have not yet been determined, so that no reliable means exists for ascertaining the differences in age of the same or closely related faunas between widely separated areas. However, as the Carboniferous is nearly everywhere characterized by an abundance of fossils, and as there is already an extensive literature on the subject, a final interpretation of the sequence of events, that will carry conviction to all workers, may very soon be looked for.

2. To the present writer, it is clear that the Permian fauna of the Urals and Timan is not the normal marine one perpetuating the Paleozoic sequence in the Mesozoic. (The same is true for Germany and England.) Of brachiopods are missing here the plicate and other types of terebratuloids other than *Dielasma* and everything from which the rhynchonelloids can be developed, spire-bearing forms and the strophomenoids of the type of the Lyttoniidæ. The same is largely true for the other classes of organisms; in fact, one can better trace the Triassic faunas of the Alps through the Ural and Timan faunas of a lower horizon, *i. e.*, those of the Schwagerina zone. These facts are admitted by Tschernyschew, but it seems to the reviewer that he fails to give proper weight to the probability which one almost wishes to state with certainty, that somewhere the Schwagerina fauna or one closely related to it continued to maintain itself, and, further, that in some region far away from the Urals and Timan it will necessarily hold a higher tratigraphic position, although somewhat changed in faunal facies. This center of dispersion was seemingly the Mediterranean region; in fact, it is the belief of the reviewer, derived from a knowledge of the Permian of Sicily and Austria, that this great body of water, Thetys, was the home of the normal marine Carboniferous and Permian faunas of Europe and Asia. From Thetys, the faunas spread to the north into the epicontinental seas of Germany and European Russia, but in

these waters, during Permian time, conditions were not favorable for the continuance of a normal marine life, and finally these faunas die out here in the gypsum and copper-depositing seas. To the south in a mediterranean, the faunas maintain themselves in a healthy and prolific condition, spread eastward across Asia and probably westward as far as El Paso, Texas; while other migrations seemingly of a somewhat different facies, but having more of the Himalayan-Arctic impress, are met with along the Pacific coasts from California far north into Arctic western America. Under these circumstances, it should not be expected that the Schwagerina zone of the Urals will hold a horizon in India or America similar to that in the Urals and Timan.

3. The question—Is there a Permian system or only a Permian formation?—is far from answered. In the area typical for the rocks under consideration, the Perm Province in the Urals of Russia, the normal marine Carboniferous fauna passes into Permian deposits of an abnormal marine character and finally into red gypsiferous shales devoid of life. Under such an enviroment, an abundance of life, with progressive or normal evolution, is excluded and, as a rule, there remains only the widely distributed species, and too often merely characterless forms are present, which do not permit safe deductions to be made in determining the chronology of a Permian system. At present, there is no acceptable sequence of faunal events for intercontinental correlation in the typical area and as far as can now be seen there will certainly be none for the closing events. The German Permian faunas are better known, but as they are clearly only a part of a great sequence and as the lower and upper stratigraphic members of this region are either devoid of fossils or have no normal marine succession, positive proof as to the entire sequence of events in a Permian system can not be looked for in this country. In England, the conditions seem to be those of Germany. In the Salt Range of India, either toward the close of the Carboniferous or early in the Permian, a great glacial period was in progress, so that in this region there are no normal marine beds in the lower part of the section; hence, no possible biological base for the system is yet apparent. On the other hand, in the central Himalayas above a vast series of Lower Carboniferous strata (5,000 feet thick), there is a marked unconformity above which occurs Permian sediments, parts of which are positively correlated with the uppermost group—the Chideru—of the Salt Range. These strata then continue without apparent break in sedimentation into the Ceratites beds of the Triassic. This time hiatus—a land interval with erosion—is probably equivalent not only to all the Upper Carboniferous but possibly also to

a part of the Productus-limestone of India. This great unconformity will be of much value in the final interpretation as to the proper position in the time scale of the entire Productus-limestone and as well the date for the period of glaciation in the late Paleozoic of India.

In America, however, in southwestern Texas, there is an unbroken section of more than 9000 feet in thickness, having more than 4000 feet of limestone, with normal marine faunas at various levels. As has been evident from the statements of Girty, this section has Carboniferous faunas of the Euro-Asiatic type, which are directly comparable with the *Spirifer marcoui*, *Omphalotrochus whitneyi*, *Productus cora*, and the *Schwagerina* zones of Tschernyschew. These Carboniferous faunas are in the lower portion of the section, above which, in the Capitan limestone, are faunas comparable with those of the Productus-limestone of India (*i.e.* faunas having *Goniocladia*, *Richthofenia*, *Lyttonia (=Leptodus)* etc.),—faunas that for some years have been regarded by several of the leading stratigraphers as the normal marine record toward the close of the Paleozoic. It is to be hoped that the U. S. Geological Survey will soon enable Dr. Girty to complete his studies, both stratigraphic and faunal, regarding this, the most complete Carboniferous and Permian section known to stratigraphers.

4. The question as to what name the closing Paleozoic system shall bear can not as yet be answered. If the rocks of the Permian area of Russia should fall into the Carboniferous, the way will open for another term for the closing system. From the accumulated evidence, there appears to be need of such a system in the classification. However, should the Permian rocks of Russia form but a member of a "Permian system" (the trend of evidence is in this direction), there would then be a choice between the Permian of Russia, the Dyas of Geinitz, the Guadalupian of Girty (Oklahomian of Keyes is rather a formation than a time term), and possibly other terms.

As workers in many countries are coming more and more to adopt a classification expressing the local physical and faunal events, the time does not seem far away when the matter of an all-embracing or world chronogenesis will have to be taken up by the International Geological Congress. Whatever the criterion for such a terminology, indicating the grander events in the world's chronogenesis, may be, it certainly can not be the one now in use, *i.e.*, the local events of a given area, the first to propose a term or terms however badly understood. A new set of system terms for general application suggested by an organization like the International Geological Congress would at once bring into use, for local areas, such despised terms as Taconic and Cambrian, and thus furnish relief from

the ever-recurring disputes concerning Lower Silurian, Cambrian, Cambro-Silurian, Ordovician, or Champlain.

5. Tschernyschew lays great stress upon the occurrence of a form of the brachiopod family Lyttoniidæ in the Schwagerina horizon of the Urals. Certainly it has great faunal value, but the acumen of Tschernyschew also led him to note the fact that it is not of the Indian genus *Lyttonia (=Leptodus)*. To it he gave the generic name *Keyserlingina*, and the few involutions of the brachia indicate that it has not yet progressed to that degree of specialization shown in the brachia of the Indian genus *Lyttonia*. In other words, *Keyserlingina* holds a lower stratigraphic horizon than *Lyttonia*. In the Austrian Alps, another primitive form of the Lyttoniidæ is found, but here the brachial folds are not laterally directed as in the other forms, but anteriorly. Hence, it is not in the direct line of evolution with the Indian genus, which has also been discovered in Nevada and at El Paso, Texas (Dr. Girty states that he also has it from the Robinson beds of California). The reviewer therefore believes that while *Keyserlingina* unmistakably indicates that the Schwagerina fauna is of the Asiatic type, it is less highly specialized than *Lyttonia*, and consequently holds a lower geological horizon.

6. In regard to Tschernyschew's conclusion that the Russian Permian brachiopods show "atavistic trends," the writer does not think it is borne out by the facts. A list of the species is given on page 31. All of the forms occur below either in the Artinsk or the Upper Carboniferous. In fact all are persisting or long-lived species and are therefore not atavistic in any phylogenetic sense. The brachiopod fauna of the typical Permian, however, may be said to be atavistic in aspect because all of the progressive forms of the Artinsk have failed to continue into this formation.

7. The reviewer, from his knowledge of the late Paleozoic brachiopods, is confident that this class of fossils can be relied on for detailed correlation of stratigraphic horizons over widely separated regions, and further on account of their persistence and wide distribution they are among the best evidence for facial affinity. The Carboniferous and Permian brachiopods are given too great specific latitude by many paleontologists, so that it is common in the literature of the subject to note that many species are found on more than one continent. *Productus semireticulatus* is believed to occur throughout all Carboniferous time and is common to the world. Such a condition permits of no exact correlation.

8. The writer can not see that the evidence as presented by Tschernyschew breaks down the laboriously attained conclusions of Waagen, Noetling, and Diener, that the Productus-

limestone (certainly the upper member or Chideru formation) is not younger than any part of the Permian of the Urals or Timan. The Schwagerina brachiopod fauna of the Urals seemingly arrives later in India, and during this interval has greatly changed. It is this altered character that dominates the faunas of the Middle and Upper Productus-limestone. This alteration is seen in the progressive development and specialization, not only of the Lyttoniidæ, but as well of the Richthofenidæ and the terebratuloids.

9. In regard to the contention of the Indian geologists and Noetling that the Indian Productus-limestone passes without stratigraphic break into the Triassic, some weight should be given to Tschernyschew's faunal argument. In Kentucky, the Devonian overlaps the Ordovician, and in Alabama, the Carboniferous the Ordovician, without visible stratigraphic break; if it were not for the fossils entombed, the maps of these regions would have shown but one formation. From the fact that not a single species is known to pass from the Productus-limestone into the higher Ceratites-bearing beds of India, one would naturally look here for a late Permian or early Triassic land interval, followed by an overlap of Triassic age. However, the fact that no unconformity nor break in sedimentation has been discovered either in the Salt Range or in the central Himalayas, and further that in the latter area there is a great unconformity between the Permian and the Lower Carboniferous (which has a thickness of 5,000 feet), are evidence rather against the supposition that the Triassic overlaps the Permian. The absence of any Permian species in these lower Ceratites beds and the rapid lithologic change between the Permian and Triassic may here be necessary conditions resulting from the great "revolution" taking place in both hemispheres between the Paleozoic and Mesozoic. It is not only the colder glacial land waters poured into the oceans of Permian time at many widely separated areas that have changed the long previous equable habitat of marine faunas, but extermination came as well through the greatly reduced continental shelves, due to the higher altitudes of the continents in the Northern Hemisphere during late Permian time. (This is especially true for North America.) In other words, the stable conditions of the Productus-limestone were interrupted by the Permian revolution going on elsewhere, killing the entire fauna of this immediate region. That this revolution did affect the Salt Range seas is seen by the change in sedimentation, and with it came extermination of its life followed very shortly by an immigration of a new but not greatly changed ammonite fauna.

ART. XVI.—*Notes on Some Eruptive Rocks in Mexico;* by F. N. GUILD, University of Arizona.

Introduction.—The central portion of Mexico is an elevated mesa or plateau extending from the United States border to the southern limits of the Republic. Its elevation varies from about 3,000 feet on the United States line to nearly 8,000 feet in the valley of Mexico. Its regularity is broken by numerous mountain ranges, some of whose peaks reach above the line of perpetual snow. The origin of this great central mesa is one of the important geological questions in Mexico to-day. Some authors* consider it to be due to great lateral fractures and uplifts, while others, though admitting that no definite explanation can be given until the region has been more thoroughly studied, are inclined towards different views.†

The eruptive rocks on this plateau are represented by enormous masses of rhyolite and andesite presenting great variations in texture, color, etc. Basalt is also abundantly developed but is of much less importance. The rhyolites and light-colored porphyritic andesites are found quite uniformly representing geologically older outflows, while the recent and modern products of volcanic activity are practically all andesites of poorly developed crystalline texture and of basaltic aspect. Excellent descriptions of many of these rocks may be found in the publications of the Geological Institute of Mexico.‡

One of the most interesting places in the whole Republic is the valley of Mexico whose interior consists of fertile sediments of great thickness derived from the disintegration of the rocks along its border and from accumulations of volcanic sand from many craters. It was formerly largely occupied by extensive lakes; Chalco, Xochimilco and Texcoco in the south, San Cristobal, Xaltocan and Zumpango in the north. Some of them have overflowed at times and inundated the city of Mexico, causing great loss of life and property. Extensive projects for draining them, begun by the Aztecs and carried out by the Spaniards and Mexicans, have finally removed all danger from this source. The valley is enclosed on all sides by eruptive masses, some of which reach an altitude of nearly

* Felix and Lenk, Beiträge zur Geol. und Paleont. der Rep. Mex., Leipzig.

† La Mesa Central de México es un fenómeno totalmente secundario y no debe referido á grandes fracturas laterales, sino que se formaba por el rellenamiento de los valles masaltos de la montaña antigua, por masas de rocas eruptivas, arenas volcánicas y aluviones modernos. "Böse, Sobre el origen de la Mesa Central Mexicana." Bul. Num. 13, El Instituto Geol. de Mex., 1899, pp. 35–49.

‡ E. Ordóñez, Las Rhyolitas de Mexico, Bul. del Ins. Geol. de Mex. Num. 14 y 15, 1900. Las Rocas Eruptivas del S. O. de la Cuenca de Mex. Bul. Num. 2, 1895.

18,000 feet above sea level, and contain numerous craters in various stages of decay. The rocks composing them are andesites and basalts with the same characteristics and variations as elsewhere in Mexico, the older outflows being of lighter color and more crystalline texture, the newer showing vitreous and darker colored types. These lavas are associated with large quantities of other products of volcanic activity such as ashes, pumiceous material, etc.

The object of this paper is to describe the mode of occurrence of some of these rocks, especially those found in and near the valley of Mexico, and to describe their mineralogical and chemical composition.

Popocatepetl.

One of the most beautiful views which greets the visitor entering the valley of Mexico, is that of two lofty peaks situated on its extreme southeastern border and reaching above the line of perpetual snow. They are called in the Aztec tongue Popocatepetl, the Smoking Mountain, and Ixtaccihuatl, the White Woman. The former is a symmetrical cone-shaped peak whose cap of dazzling white presents a strong contrast to the dark pine forests of the lower slopes. Ixtaccihuatl is less symmetrical and has an irregular elongated summit.

It is said that the first ascent of Popocatepetl was made by one of the captains of Cortes in 1521; one of the men is reported to have been let down into the crater by a rope for the purpose of collecting sulphur to make gunpowder for carrying on the conquest.* At the present time frequent ascents are made and a well-equipped party experiences no serious discomforts.

The height of the peak above sea level is 17,876 feet, and it has the form of a symmetrical cone obliquely truncated. Its slopes may be divided into three parts, a lower area of vegetation reaching to about 12,000 feet, then steep slopes of soft volcanic sand with occasional ridges of dark andesite up to about 14,000 feet, and finally the snow cap reaching to the crater. The latter is probably not very thick, since there are no crevasses or other evidences of glacial movements.

The crater is elliptical in shape with a maximum diameter of 612 meters and a minimum diameter of 400 meters.† The inner rim is made up of irregular ledges or blocks of black andesite, with a slope towards the crater of about 20 meters, and then there is a perpendicular cliff varying from 80 to 75 meters in height. At its base is a talus slope extending towards the center of the crater, which contains a small pond formed by the

* Prescott, Conquest of Mexico, p. 44, vol. ii.

†Aguilera y Ordóñez, Expedicion Cientifica al Popocatepetl, Mexico, 1895.

melting of the snow. The maximum depth of the crater from the surface of the lake to the highest point of the rim is said to be 505 meters. At the malecate, or hoist, formerly used in extracting sulphur from the crater, the depth is considerably less, being but 205 meters.* The bottom of the crater contains several small solfataras, from which steam and sulphur vapor escape. It is impossible to enter the crater except by means of a rope down a perpendicular cliff 250 feet high. The descent, however, has been made by members of the Geological Institute of Mexico, who spent forty-eight hours in the crater investigating it.* The interior heat of the volcano is still sufficient to prevent the crater becoming filled up with snow.

FIG 1. Popocatepetl, a bank of volcanic ash projecting through the snow. About 1000 ft. below the crater.

The rocks of Popocatepetl† consist of andesites and basalts with the usual accompanying pumiceous and scoriaceous forms, which are especially well developed immediately below the snow line, where many barrancas, or deep cuts, commence and radiate outward, giving an excellent opportunity for studying it. One of the deepest of them, the Barranca de Tlamacas, cuts through this material to the depth of 200 feet or more and exposes beds made up alternately of fine volcanic ash and coarse pumiceous

* Aguilera y Ordóñez, Expedicion Cien. al Popocatepetl.

† An excellent account of an ascent of Popocatepetl, with observations upon its geography and geology with a brief description of its lavas, has been given by Farrington—Geological Series of the Field Columbian Press, vol. i, No. 2, 1897.

matter. In the lapilli there are frequently embedded blocks of black compact lava which have evidently rolled down from above. Narrow ledges of lava are occasionally found projecting above the sand and mark the position of some outflow from the crater which has solidified before reaching the base of the volcano. (Fig. 2.)

Petrography of the andesites of Popocatepetl.—The results of the petrographic study of four specimens collected from various places will be given as illustrative of the variations in these andesites.

No. 1 was from one of the large blocks at the rim of the crater near the Malacate. Hand specimens appear as black

FIG. 2. Popocatepetl, showing a ridge of black andesite projecting through the volcanic sand. Near the snow line.

basaltic rocks containing numerous phenocrysts of feldspar averaging about two millimeters in diameter, rather rounded in outline and evenly distributed. One square centimeter of surface usually contains about fifteen phenocrysts. Under the microscope the feldspar appears as broken fragments and idiomorphic crystals presenting the ordinary characteristics of rocks of this type; zonal structure, abundant inclusions of the dark groundmass, and twinning according to the albite and pericline laws. Optical determinations place some of the crystals in the andesine-oligoclase, others in the andesine-labradorite series. The chemical analysis given below shows that the feldspars, taken as a whole, are of rather more acid type than the phenocrysts,

which is doubtless due to more acid plagioclases in the groundmass. Pyroxene is present in both orthorhombic and monoclinic varieties. Some are slightly pleochroic. The groundmass is a dark, nearly opaque glass.

No. 2 was also taken from the rim of the crater. It is more compact and contains much less conspicuous phenocrysts. The microscope shows the same mineralogical composition as in No. 1. The feldspar is developed in much smaller crystals and twinning and zonal structure is not marked. Nearly all of the crystals are filled with inclusions of the groundmass.

No. 3 was taken some distance below the snow line from a large ledge near Tlamacas and extending towards the north. Hand specimens appear as medium dark gray rocks of non-porphyritic structure. The material is very uniform in different portions of the same mass and probably represents an outflow of considerable extent. Green crystals of pyroxene and occasionally a small fragment of feldspar can be seen without the microscope. An optical study shows that the crystals are well formed and possess sharp angular outlines. Zonal structure and twinning are both developed as in No. 1, but the pyroxenes are much more abundant and hypersthene greatly predominates over augite. The groundmass is a felt of magnetite, pyroxene microlites and obscure feldspar rods. An optical determination of the feldspar crystals makes them mostly labradorite of medium acidity, though a few belong to less basic types.

No. 4 was taken from the Barranca de Tlamacas. It may be classified as a dark yellowish gray to brown andesitic pumice. It is filled with large cavities one or two centimeters in diameter, at or near the center of which is frequently to be found a small rounded mass of dark glassy material sometimes containing a few phenocrysts and supported by radiating threads of delicate glass which appear not unlike spiders' webs. The microscope shows this rock to be made up mostly of threads and fragments of light yellow glass with only an occasional crystal of feldspar or pyroxene.

Many other specimens, collected from various points about the volcano, show practically the same mineralogical composition as those described but with variations in structure and texture due doubtless to more or less rapid cooling rather than to difference in chemical composition. Basalts and trachites have been described from Popocatepetl by Aguilera and Ordoñez. The basalts occur as representatives of older outflows and are not at all abundantly represented. The writer did not observe any occurrences of this type of rock during his recent expedition to the volcano. Specimens, however, studied at the Instituto Geologico de Mexico, through the kindness of the Director, appear as typical fine-grained basalt with abundant olivine. The latter mineral is sometimes devel-

oped in unusually large phenocrysts. The trachites of Popocatepetl might better be described as andesites with trachitic texture since plagioclase seems to predominate.

The chemical composition of the hypersthene-andesites from Popocatepetl is shown by two analyses made by the writer. The first (No. 1, described above) represents a recent outflow, the other (No. 3, from near Tlamacas) is representative of an earlier period of activity.

	No. 1.	No. 3.
SiO_2	62·51	58·07
Al_2O_3	16·62	15·83
Fe_2O_3	1·12	2·97
FeO	3·75	3·89
MgO	3·30	5·56
CaO	5·10	6·70
Na_2O	4·28	3·89
K_2O	1·86	1·73
H_2O. Above 110	·53	·23
H_2O. Below 110	·15	·18
TiO_2	1·02	1·27
P_2O_5	·23	·29
Cr_2O_3	·015	·01
MnO	·10	·06
SrO	·03	·04
BaO	·14	·07
Li_2O	trace	trace
	100·755	100·79

The normative mineralogical composition and position of the rock according to the quantitative classification is given in the table below.

No. 1.

Quartz, SiO_2			13·98%
Orthoclase, $K_2O.Al_2O_3.6SiO_2$			11·12
Albite, $Na_2O.Al_2O_3.6SiO_2$			36·16
Anorthite, $CaO.Al_2O_3.2SiO_2$			20·57
Diopside	$FeO.SiO_2$	·52	3·27
	$CaO.SiO_2$	1·62	
	$MgO.SiO_2$	1·00	
	$MnO.SiO_2$	·13	
Hypersthene	$MgO.SiO_2$	7·20	10·90
	$FeO.SiO_2$	3·70	
Magnetite, $FeO.Fe_2O_3$			1·86
Ilmenite, $FeO.TiO_2$			1·82
Apatite			·31
Rest			·86
			100·85

$$\frac{Sal}{Fem} = \frac{81{\cdot}83}{18{\cdot}16}, < \frac{7}{1} > \frac{5}{3}, \text{ Class II, Dosalane}$$

$$\frac{Q}{F} = \frac{13{\cdot}98}{67{\cdot}85}, < \frac{3}{5} > \frac{1}{7}, \text{ Order 4, Austrare}$$

$$\frac{K_2O+Na_2O}{CaO} = \frac{89}{74}, < \frac{5}{3} > \frac{3}{5}, \text{ Rang 3, Tonalase}$$

$$\frac{K_2O}{Na_2O} = \frac{20}{69}, < \frac{3}{5} > \frac{1}{7}, \text{ Subrang 4, Tonalose}$$

No. 3.

Quartz, SiO_2			8·88%
Orthoclase, $K_2O.Al_2O_3.6SiO_2$			10·01
Albite, $Na_2O.Al_2O_3.6SiO_2$			32·49
Anorthite, $CaO.Al_2O_3.2SiO_2$			20·85
Diopside	$CaO.SiO_2$	4·52	8·58
	$FeO.SiO_2$	·66	
	$MgO.SiO_2$	3·40	
Hypersthene	$MgO.SiO_2$	10·40	12 51
	$FeO.SiO_2$	2·11	
Magnetite, $FeO.Fe_2O_3$			4·18
Ilmenite, $FeO.TiO_2$			2·28
Apatite			·62
Rest			·59
			100·99

$$\frac{Sal}{Fem} = \frac{72{\cdot}23}{28{\cdot}17}, < \frac{7}{1} > \frac{5}{3}, \text{ Class II, Dosalane}$$

$$\frac{Q}{F} = \frac{8{\cdot}88}{63{\cdot}35}, < \frac{3}{5}, \text{ Order 4–5} \begin{cases} \text{Austrare} \\ \text{Germanare} \end{cases}$$

$$\frac{K_2O+Na_2O}{CaO} = \frac{80}{75}, < \frac{5}{3} > \frac{3}{5}, \text{ Rang 3} \begin{cases} \text{Tonalase} \\ \text{Andase} \end{cases}$$

$$\frac{K_2O}{Na_2O} = \frac{18}{62}, < \frac{3}{5} > \frac{1}{7}, \text{ Subrang 4} \begin{cases} \text{Tonalose} \\ \text{Andose} \end{cases}$$

Sierra de Guadalupe.

The regularity of the valley of Mexico is broken in many places by branches extending from the high mountain ranges and reaching in some cases almost to the city of Mexico. One of the most conspicuous of these is the Sierra de Guadalupe located directly north of the city, and consisting of a series of rounded hills of low altitude (fig. 3). The three elevations nearest the city of Guadalupe are known as Cerro de Guerrero, Cerro de San Isabel and Cerro de Chiquihuite. At the base,

especially in the vicinity of the city, they are composed of rocks presenting the appearance of volcanic breccia with cementing material of a dark vitreous andesite, with sometimes small phenocrysts of feldspar; the fragments are of very much the same material with occasionally lighter colored and more porphyritic varieties. The most common type is that of a dark brown to black compact rock, with a few visible phenocrysts of green pyroxene. These rocks are nearly all opal-bearing, the

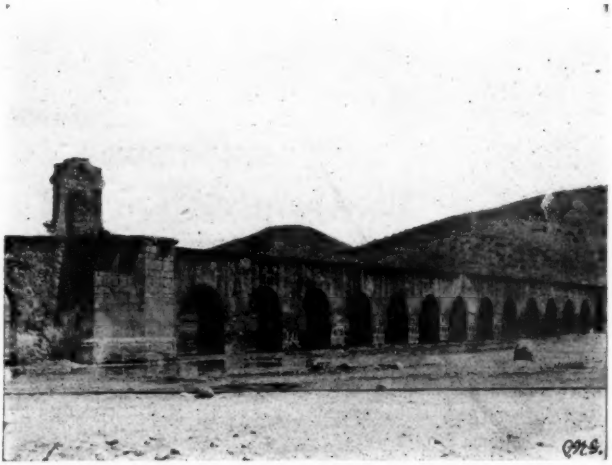


FIG. 3. A view of the Sierra de Guadalupe. Aqueduct of Guadalupe in the foreground.

mineral occurring in cracks and occasionally in amygdaloidal cavities.* It is usually colorless (hyalite), but sometimes presents various shades of yellow, red and blue. More porphyritic types of these andesites occur in other portions of the series.

Microscopically these rocks are similar to those from Popocatepetl and are hypersthene andesites. While there is great mineralogical similarity in the specimens from different places, there is also great diversity in the arrangement of the constituents, variations in texture due to more or less rapid cooling. The feldspar appears as rods, broken fragments, and larger crystals with zonal structure frequently possessing a clear border, but containing dark inclusions in the interior. The

* For an excellent description of the occurrence of opal in the eruptive rocks of Mexico, and how they are frequently found filling decayed spherulitic growths, see, Las Rhyolitas de Mexico, Bul. Num. 14 y 15, Inst. Geol. de Mex.

groundmass varies from a pure glass swarming with crystallites to a semi-crystalline condition, frequently containing obscure globulitic and microlitic growths. Hypersthene andesites of this type have been described from Crater Lake, Oregon,* and other portions of the United States.

Colima de Chapultepec.

This is a small rocky eminence rising abruptly from the plains, about three miles southwest of the city of Mexico. On the summit is the beautiful castle of Chapultepec, and around its base are artificial lakes and roadways which make it one of the most beautiful parks in the world. Although isolated, it is considered to belong topographically to the Sierra de las Cruces, a range bounding the valley on the southwest.† Specimens collected from it appear as dark gray mottled rocks with porphyritic hornblendes and feldspars, the latter being most conspicuous. Under the microscope both feldspar and hornblende are found to occur in two generations, the feldspar in large idiomorphic crystals with zonal structure, and symmetrically arranged inclusions and smaller rod-shaped growths; the hornblende is in elongated crystals and is of a basic variety possessing strong pleochroism and dark to opaque borders. The groundmass is partly crystallized, containing needles of both hornblende and feldspar with patches of transparent glass. (A, fig. 5, p. 172.)

An analysis of this rock was made by the writer with the following results:

Analysis of Hornblende Andesite from Chapultepec.

SiO_2	62·89%
Al_2O_3	16·42
Fe_2O_3	2·64
FeO	2·24
MgO	2·50
CaO	4·77
Na_2O	4·07
K_2O	2·15
H_2O. Above 110	1·00
H_2O. Below 110	·55
TiO_2	·83
P_2O_5	·20
Cr_2O_3	·01
MnO	·08
SrO	·03
BaO	·07
Li_2O	Trace
	100·45

* Diller & Patton, The Geology and Petrography of Crater Lake National Park, U. S. Geol. Sur. PP No. 3, plate xv.

† Ordóñez, Bul. Num. 2, Ins. Geol. de Mex.

Normative Mineralogical Composition and Classification.

Quartz, SiO_2			17·52%
Orthoclase, $K_2O.Al_2O_3.6SiO_2$			12·79
Albite, $Na_2O.Al_2O_3.6SiO_2$			34·58
Anorthite, $CaO.Al_2O_3.2SiO_2$			20·02
Diopside	$MgO.SiO_2$	·90	2·18
	$FeO.SiO_2$	·13	
	$CaO.SiO_2$	1·15	
Hypersthene	$MgO.SiO_2$	5·40	5·93
	$FeO.SiO_2$	·53	
Magnetite, $FeO.Fe_2O_3$			3·71
Ilmenite, $FeO.TiO_2$			1·50
Apatite			·30
Rest			1·74
			100·27

$$\frac{Sal}{Fem} = \frac{84{\cdot}91}{13{\cdot}62}, < \frac{7}{1} > \frac{5}{3}, \text{ Class II, Dosalane}$$

$$\frac{Q}{F} = \frac{17{\cdot}52}{67{\cdot}39}, < \frac{3}{5} > \frac{1}{7}, \text{ Order 4, Austrare}$$

$$\frac{K_2O + Na_2O}{CaO} = \frac{89}{72}, < \frac{5}{3} > \frac{3}{5}, \text{ Rang 3, Tonalase}$$

$$\frac{K_2O}{Na_2O} = \frac{23}{66}, < \frac{3}{5} > \frac{1}{7}, \text{ Subrang 4, Tonalose}$$

Basaltic lava sheets.

The extreme southern portion of the valley of Mexico in the vicinity of Tlalpam is flooded with an enormous outflow from the craters of Zeutli, Xicalco and Xitli. Although no records are preserved in the ancient Aztec's writings regarding eruptions from these volcanoes, there are abundant evidences showing their recent origin. The lavas are in a very fresh condition and human bones and implements are found beneath them. Their surfaces are very rough, consisting of bowlders and loose fragments of all sizes. Compact and scoriaceous modifications are both represented. The most common type is an exceedingly fine-grained black rock lacking phenocrysts, but filled with numerous small cavities, and containing frequent inclusions of other rocks, usually andesitic in character, especially where the lava stream has encroached upon elevations representing older outflows, as in the vicinity of Cerro de Xochitepetl.

Microscopically the rock is a typical fine-grained basalt with about equal quantities of olivine and pyroxene, both of which are clear and undecomposed, and rather difficult to distinguish from one another, since the pyroxene is orthorhombic. The remainder of the rock is made up of fine rods of feldspar crowded together and pressed against the larger crystals of olivine and hypersthene, together with magnetite, and considerable dark isotropic matter. The writer has described basalts of this texture from Arizona,* and they are common in other parts of the United States.

FIG. 4. Columns in Basalt, Salto de San Anton, Cuernavaca.

A section was prepared from one of the large inclusions of andesite in the basalt near Xochitepetl (B, fig. 5, p. 172). In general the structure and composition is similar to that of the andesite of Chapultepec. Hornblende and plagioclase are developed in well formed crystals. The hornblende has been the first to decompose, and some crystals are nearly opaque from the separation of magnetite.

Basaltic outflows similar to the ones described above are found in the vicinity of Cuernavaca, and in places, as at the Salto de San Anton, have a beautiful columnar structure (fig. 4). An analysis of the basalt from this locality shows it to have the composition given below.

* Petrography of the Tucson Mountains, this Journal, xx, p. 313, pl. ix.

Analysis of Basalt from El Salto de San Anton.

SiO_2	51·56%
Al_2O_3	15·24
Fe_2O_3	2·73
FeO	5·99
MgO	8·30
CaO	7·67
Na_2O	3·74
K_2O	1·25
H_2O. Above 110	·16
H_2O. Below 110	·15
TiO_2	1·81
P_2O_5	·47
Cr_2O_3	·005
MnO	·15
SrO	·05
BaO	·07
Li_2O	Trace
	99·945

Normative Mineralogical Composition and Classification.

Orthoclase, $K_2O.Al_2O_3.6SiO_2$			11·12%
Albite, $Na_2O.Al_2O_3.6SiO_2$			31·44
Anorthite, $CaO.Al_2O_3.2SiO_2$			19·18
Diopside	$CaO.SiO_2$	6·38	12·17
	$MgO.SiO_2$	4·60	
	$FeO.SiO_2$	1·19	
Hypersthene	$MgO.SiO_2$	5·10	6·81
	$FeO.SiO_2$	1·45	
	$MnO.SiO_2$	·26	
Olivine	$2MgO.SiO_2$	7·70	10·15
	$2FeO.SiO_2$	2·45	
Magnetite, $FeO.Fe_2O_3$			3·94
Ilmenite, $FeO.TiO_2$			3·34
Apatite			1·24
Rest			·43
			99·82

$$\frac{\text{Sal}}{\text{Fem}} = \frac{61{\cdot}74}{37{\cdot}65}, < \frac{5}{3} > \frac{3}{5}, \text{ Class III, Salfemane}$$

$$\frac{\text{F}}{\text{Q}} = 61{\cdot}74, \quad > \frac{7}{1}, \text{ Order 5, Gallare}$$

$$\frac{\text{K}_2\text{O}+\text{Na}_2\text{O}}{\text{CaO}} = \frac{80}{69}, < \frac{5}{3} > \frac{3}{5}, \text{ Rang 3, Comptonase}$$

$$\frac{\text{K}_2\text{O}}{\text{Na}_2\text{O}} = \frac{20}{60}, < \frac{3}{5} > \frac{1}{7}, \text{ Subrang 4, Comptonose}$$

Sierra Catarina, one of the most interesting features in the valley of Mexico, consists of a series of crater cones rising abruptly from the level plains in the southeastern part of the valley. Some are in groups of four or five, while others are isolated truncated cones with an average height of 400 feet. Five of them were visited by the writer during the summer of 1905, and all but one were found to have a well defined crater on the summit. Their component material varies from pure volcanic sand to compact lava, while scoriaceous forms, lapilli and volcanic blocks of all sizes are abundant. A compact lava is found near the base of several of them but has never flowed to great distances. The predominating color is black for the compact varieties of lava and black or red for the more scoriaceous modifications—porphyritic types are entirely lacking.

Las Calderas, perhaps the best known of these crater cones, is about one mile south of the railroad station of Los Reyes. It is an elongated truncated cone with a sloping summit due to the erosion of the rim on the southern extremity. The cone contains two craters with a narrow rim between them. Barometric observations gave the following elevations:

Highest point on the rim, 650 feet above the plain.
Lowest point on the rim, 275 feet above the plain.

The bottom of the crater was found to be at practically the same level as the surrounding plain, its diameter is about 1,500 feet and its interior walls are quite precipitous.

This cone consists almost entirely of a yellowish gray stratified tuff of about the hardness of adobe brick and with an occasional volcanic block embedded in it. Microscopically the ash is made up mostly of transparent glass with some microlites of feldspar and decomposed particles of ferromagnesian minerals. The volcanic block mentioned above contains small and rather scattered rods of feldspar in an exceedingly dark, glassy, structureless groundmass. Ferromagnesian minerals are present only in isolated grains. The rock is of too vitreous a nature to admit of accurate classification from its mineral constituents.

Directly southwest of Las Calderas is a series of crater cones the best formed of which is called Cerro de Catarina. The

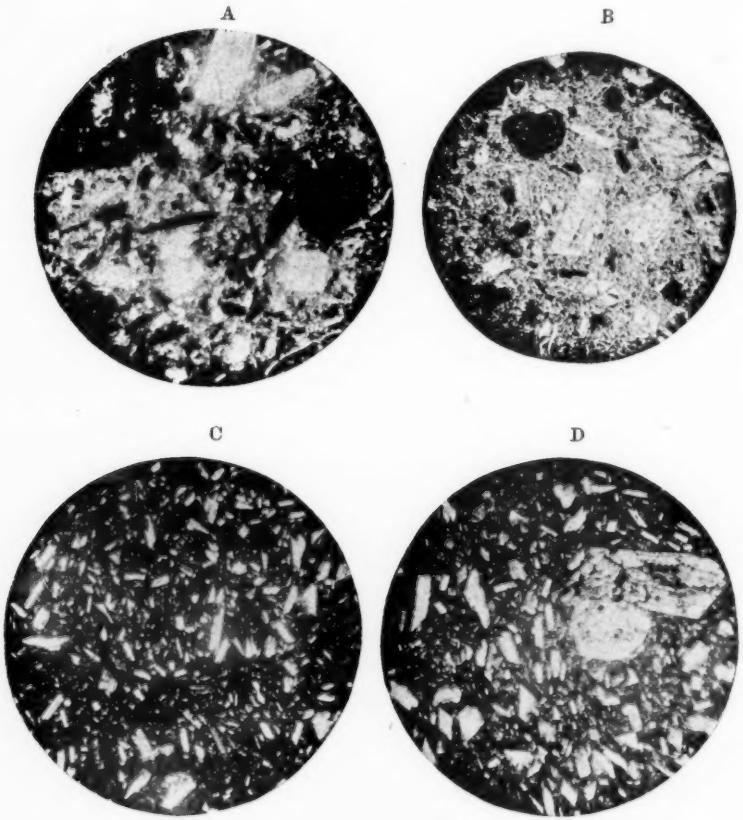


FIG. 5. Description of Photomicrographs illustrating the types of andesites in the valley of Mexico.

A. Porphyritic hornblende andesite from Chapultepec, showing both feldspar and hornblende in two generations. The groundmass is nearly all crystallized material. 14 diameters.

B. Hornblende andesite from Xochitepetl. Zonal structure in feldspar. Crystalline groundmass. Crossed nicols. 14 diameters.

C. Andesite of basaltic aspect from Popocatepetl. Abundant feldspar and less pyroxene in a vitreous groundmass. Pyroxene cannot be distinguished from feldspar in the cut. 14 diameters.

D. Andesite of basaltic aspect from Sierra de Guadalupe showing a large hypersthene with smaller feldspar crystals in a semi-vitreous groundmass. 14 diameters.

A and B are light-colored porphyritic andesites representing an old outflow of great extent. C and D are megascopically non-porphyritic and belong to an outflow of recent date.

approach to them from Los Reyes is over an exceedingly rough bow of compact lava.

Several specimens were collected from this elevation, one of a lustrous black rock with conchoidal fracture and free from cavities or inclusions. Others collected from the loose material around the crater were more scoriaceous and contained many cavities. Under the microscope they all show about the same characteristics, the chief variation being in the relative amount

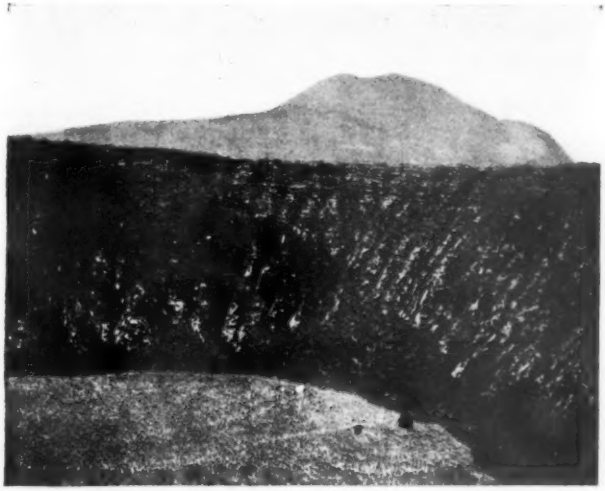


FIG. 6. View taken from the interior of the crater of Las Calderas, showing the walls and stratified condition of the volcanic ash.

of glass present. The description of the block found on Las Calderas applies to most of the fragments found near the summit of Catarina. The rock of the rough lava flow mentioned above, while probably of the same mineralogical composition, has quite a different texture. It is basaltic, consisting of dark glass swarming with minute rods of feldspar. The rods are not pressed together as is usual in these types of rock but each individual appears quite distinct from its neighbor.

Cerro Xaltepetl, located still further south, is similar to the last described cone except that it is of less altitude, contains a greater quantity of the finer products of volcanic activity and the outflow of lava at the base is lacking, and there are stratified beds of ash in its place. Sections prepared from volcanic blocks, lapilli and scoriaceous material reveal nothing new as compared with that from the other cones of the same group. The crater is very shallow and probably not more than 500

feet across; the soil formed at its bottom is very fertile and these craters seem to be favorite places for cultivating corn.

Next in line in this interesting group of volcanoes is Cerro de San Nicolas, one of the smallest but most symmetrical of the cones. It is about 350 ft. high, as found by barometric measurements, and contains a small crater possibly 50 feet deep. The material ejected from this crater both from a megascopic and microscopic standpoint presents about the same characteristics as in the last two cones.

About three miles from San Nicolas is another low elevation called Cerro de Ixtapalapa whose crater has been completely removed by erosion. Near the summit the component material is the same as that of the other craters of the group, but its base is of compact lava which has spread out for some distance forming gentle slopes. In this respect Cerro de Ixtapalapa resembles Cerro de Catarina more than the other cones. Under the microscopes this compact lava is more crystallized than any of the others examined. Feldspar occurs in two distinct generations although no phenocrysts can be detected by the naked eye. Orthorhombic pyroxene is abundantly developed in the form of isolated crystals and clusters. This rock resembles quite closely those already described from the Sierra de Guadalupe. It may be called a hypersthene andesite.

Summary.

It will be seen from the foregoing descriptions that the valley of Mexico and vicinity represent a petrographic province in which the intermediate and basic types of rocks are abundantly developed. In this respect it resembles regions of recent volcanic activity in the western portion of the United States and other parts of the world. The hypersthene andesite from Popocatepetl and the Sierra de Guadalupe are very similar to those described from Crater Lake, Ore.,* Mt. Shaster, Cal.,† Buffalo Peak, Col.,‡ and other well known localities. Further the material ejected from Colima§ and other active volcanoes in Mexico during their recent periods of eruption seems to be of the same general mineralogical composition. The chemical composition is also similar, as may be observed by comparing the analyses accompanying this paper with those from the localities mentioned above. It is interesting to observe the relation between the chemical composition of the older crystalline andesites as illustrated by the rock from Chapultepec, and the newer, non-porphyritic, more vitre-

* Diller and Patton, The Geology and Petrography of Crater Lake National Park. PP No. 3, U. S. Geol. Sur.

† Diller, U. S. Geol. Sur. Bul. No. 150, p. 227.

‡ Cross, U. S. Geol. Sur. Bul. No. 150, p. 224.

§ Ordóñez, Les Dernières Eruptions du Volcan de Colima, Mexico, 1903. Also a review by the writer in Geologisches Centralblatt, Bd. VII, No. 8.

ous and basaltic-like lava from Popocatepetl. These are almost identical in chemical composition yet have given rise to dissimilar mineralogical developments. The one has developed abundant hornblende, the other pyroxene. This of course is easily explained on the ground that the consolidation has taken place under diverse conditions, the one being erupted in large masses which formed mountain ranges and so cooling very slowly and under great pressure, the other in small outflows which in some cases barely spilled over the rim of the crater. Farrington* in comparing the rocks of Popocatepetl and Ixtaccihuatl speaks of the remarkable fact that they differ completely in character, the one being hypersthene andesite and the other a quite dissimilar appearing hornblende andesite. It is quite possible that in this case as in the one mentioned above a similar chemical composition is masked by a dissimilar mineralogical structure. This view is further substantiated by comparing the analysis given above (No. 1) with an incomplete analysis of hornblende andesite from Ixtaccihuatl made by Felix and Lenk.† As is well understood, hornblende requires for its formation unusual conditions of pressure, etc., while the pyroxenes do not. The recent lavas of Popocatepetl are more acid in composition than the old. The few basalts are mostly covered up by andesitic outflows. The older andesite of Tlamacas is of a more basic type than those collected about the rim of the crater.

Volcanic sand and ashes are developed in enormous quantities around the base of the older mountains in many places in Mexico, and constitute one of the chief sources of the great fertility of the soil. The writer has been told that after the coffee plantations in that country have become covered for many square miles with a thin mantle of gray ash from the volcanoes, contrary to the expectations of the haciendadoes the soil has been improved and better yields experienced. The older volcanic sands frequently become cemented and constitute a material of sufficient strength to be used as a building stone. It is often so soft that it can be worked into various shaped bricks by means of a hatchet, and not infrequently becomes harder on exposure to the air. The texture varies from a fine-grained stratified deposit like that described from Las Calderas, to rounded semi-pumiceous grains somewhat larger than peas cemented by finer material. Many of the varieties frequently have a peculiar, not unpleasing and rusty appearance. Intermediate varieties sometimes show oolitic structures.

* Op. cit., p. 109.

† SiO_2 61·24, Al_2O_3 18·32, Fe_2O_3 and FeO 6·17, MgO 3·76, CaO 5·06, Na_2O 3·15, K_2O 2·37, H_2O 0·67, Felix und Lenk, Btr. Geol. Mex., II, p. 229, 1899.

ART. XVII.—*The Hydrolysis of Salts of Iron, Chromium, Tin, Cobalt, Nickel, and Zinc in the Presence of Iodides and Iodates;* by SETH E. MOODY.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—cxlvi.]

Iron.

IT has been shown in a former paper* that the action of a mixture of potassium iodide and potassium iodate upon aluminium chloride and aluminium sulphate may serve as the basis for the iodometric determination of aluminium.

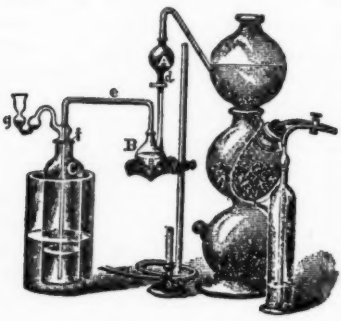
Just as salts of aluminium are hydrolyzed in the presence of the iodide-iodate mixture with the liberation of iodine, so are salts of iron. The reaction by which ferric sulphate is hydrolyzed is similar to that for the hydrolysis of aluminium chloride and aluminium sulphate, as already given.

$$Fe_2(SO_4)_3 + 5KI + KIO_3 + 3H_2O = 2Fe(OH)_3 + 3K_2SO_4 + 6I.$$

The hydrolysis of ferrous sulphate is accompanied by oxidation of the ferrous hydroxide at the expense of the iodate, as follows:

$$3FeSO_4 + 5KI + KIO_3 + 3H_2O = 3Fe(OH)_3 + 3K_2SO_4 + 6I$$
$$6Fe(OH)_2 + KIO_3 + 3H_2O = 6Fe(OH)_3 + KI.$$

The iodine eliminated is an exact measure of such hydrolysis as in the case of aluminium and becomes known by the use of a standard solution of sodium thiosulphate for its titration.



A solution of ferrous sulphate was used in the experiments performed, made up to about N/10 strength. Its value was obtained with potassium permanganate as shown in Table I. Of this solution portions of 25$^{cm^3}$ were drawn from a burette into a Voit flask, the iodide-iodate mixture added and the whole boiled for 30 minutes in the presence of a current of hydrogen to transfer the iodine to the receiver, a Drexel flask charged with potassium iodide, when it was estimated with a standard solution of sodium thiosulphate.

Table II shows results of these experiments.

* This Journal, xx, 1905, p. 181.

TABLE I.

$FeSO_4$. cm^3.	$K_2Mn_2O_8$. cm^3	Fe. grm.	Iodine equivalent. grm.	grm. (Mean.)
25	10·60	0·0734	0·3326	
25	10·60	0·0734	0·3326	
25	10·57	0·0732	0·3317	0·3322
25	10·58	0·0733	0·3320	
25	10·59	0·0734	0·3323	

TABLE II.

$FeSO_4$. cm^3.	KI. grm.	KIO_3. cm^3.	Time in minutes.	$Na_2S_2O_3$. cm^3.	Iodine calculated. grm.	Diff. grm.
25	1·0	15	30	26·67	0·3324	+0·0002
25	1·0	15	30	26·68	0·3325	+0·0003
25	1·0	15	30	26·65	0·3321	−0·0001
25	1·0	15	30	26·67	0·3324	+0·0002
25	1·0	15	30	26·66	0·3323	+0·0001

So it appears that the hydrolysis of ferrous sulphate is complete in the presence of the iodide-iodate mixture and that the iodine set free is an exact measure of the SO_4-ion present and of the iron in the ferrous sulphate of ideal composition.

Chromium.

Chromium sulphate, in the form of the alum, was next examined. The standard of the solution was found by precipitating with ammonia and igniting the chromic hydroxide to constant weight. For the purpose of comparison other portions of the solution were treated with the iodide-iodate mixture and boiled for half an hour in a trapped Erlenmeyer beaker to expel the iodine. A few drops of sodium thiosulphate were added to take up the last trace of iodine and thus insure complete hydrolysis. The precipitate was filtered off on asbestos, washed with boiling water and ignited to constant weight. Results of these experiments are given in the following table:

TABLE III.

Approx. N/10 chrome alum.	Precipitant. Ammonia. Cr_2O_3 found.	Iodide-iodate mixture. Cr_2O_3 found.	Mean of entire series.
cm^3	grm.	grm.	grm.
25	0·0643	0·0638	
25	0·0638	0·0645	
25	0·0646	0·0641	0·0642
25	0·0641	0·0640	
25	0·0644	0·0643	

The sulphuric acid set free by hydrolysis upon boiling with the iodide mixture was then found by the iodide-iodate reaction, one gram of potassium iodide being in each case dissolved in 10^{cm^3} of a solution of potassium iodate (30 grms. to a liter) and added to the measure of chrome alum in the Voit flask. The mixture was boiled thirty minutes with a current of hydrogen to aid in removing the iodine liberated to the Drexel flask containing about 3 grams of potassium iodide dissolved in water. The iodine collected in the receiver was estimated with sodium thiosulphate as in previous experiments. That the hydrolysis of the sulphate had been complete was shown by dissolving the washed precipitate in nitric acid and testing the solution with barium chloride, no barium sulphate being found.

TABLE IV.

Approx. N/10 chrome alum. cm^3.	Time in minutes.	$Na_2S_2O_3$. cm^3.	I. grm.	Cr_2O_3 corresponding to SO_3, equivalent of iodine set free. grm.	Excess of Cr_2O_3 (Basic.) grm.
25	30	23·50	0·2915	0·0583	0·0059
25	30	23·45	0·2908	0·0582	0·0060
25	30	23·40	0·2902	0·0580	0·0062
25	30	23·45	0·2008	0·0582	0·0060
25	30	23·44	0·2907	0·0581	0·0061

The fact that more chromic oxide is contained in the alum than corresponds to the SO_3 found by the iodide-iodate reaction in the complete hydrolysis of the salt shows at once that this particular preparation of chrome alum, like many ordinary commercial alums, is basic.

Tin.

In experimenting with salts of tin the difficulty is to obtain a salt of definite composition with which to start. The double salt of stannic chloride and potassium chloride was selected as a suitable salt for determining the character of the hydrolysis of stannic chloride. This salt was prepared by adding stannic chloride to a cold saturated solution of potassium chloride. The material was then filtered, washed and dried in a vacuum desiccator.

The tin content of this salt was found by precipitating stannic acid with the iodide-iodate mixture, igniting and weighing the stannic oxide thus obtained. Results of these experiments follow in Table V.

TABLE V.

$SnCl_4$. 2KCl. grm.	KI. grm.	KIO_3 cm^3	SnO_2 precipitated. grm.	Mean of entire series. grm.
0·25	1·0	15	0·0926	
0·25	1·0	15	0·0933	
0·25	1·0	15	0·0937	
0·25	1·0	15	0·0929	0·0931
0·25	1·0	15	0·0932	
0·25	1·0	15	0·0930	
0·25	1·0	15	0·0934	
0·25	1·0	15	0·5931	

Portions of this salt were placed in the Voit flask with the iodide-iodate mixture, and the mixtures were boiled for 40 minutes in a current of hydrogen to transfer the iodine to the Drexel flask charged with potassium iodide. The iodine thus eliminated was estimated with a standard solution of sodium thiosulphate of approximate N/10 strength. The results are given in A of the following table.

An abundance of iodine is liberated immediately upon the addition of the iodide-iodate mixture without boiling, and in order to see to what limit the action might go at the ordinary temperature of the room, a series of experiments was made in which the iodine was removed at once with sodium thiosulphate, and the solution after standing two hours was titrated with sodium thiosulphate, the total amount of the thiosulphate used being a measure of the iodine eliminated in the reaction and a measure of the tin present.

The results of these experiments are given in B of the table which follows:

TABLE VI.

$SnCl_4$. 2KCl. grm.	KI. grm.	KIO_3. cm^3.	Time in minutes.	Approx. N/10 $Na_2S_2O_3$. cm^3.	I. grm.	SnO_2 calculated. grm.	SnO_2 precipitated. grm.	Diff. grm.
				A				
0·25	1·0	15	40	24·37	0·3137	0·0933	0·0931	+0·0002
0·25	1·0	15	40	24·36	0·3135	0·0933	0·0931	+0·0002
0·25	1·0	15	40	24·32	0·3130	0·0932	0·0931	+0·0001
0·25	1·0	15	40	24·33	0·3132	0·0932	0·0931	+0·0001
0·25	1·0	15	40	24·36	0·3135	0·0933	0·0931	+0·0002
0·25	1·0	15	40	24·35	0·3134	0·0933	0·0931	+0·0002
0·25	1·0	15	40	24·34	0·3133	0·0932	0·0931	+0·0001
0·25	1·0	15	40	24·36	0·3135	0·0933	0·0931	+0·0002

TABLE VI (continued).

$SnCl_4$. 2KCl. grm.	KI. grm.	KIO_3. cm^3.	Time in minutes.	Approx. N/10 $Na_2S_2O_3$. cm^3.	I. grm.	SnO_2 calculated. grm.	SnO_2 precipitated. grm.	Diff. grm.
				B				
0·25	1·0	15	120	24·37	0·3137	0·0933	0·0931	+0·0002
0·25	1·0	15	120	24·35	0·3134	0·0933	0·0931	+0·0002
0·25	1·0	15	120	24·34	0·3133	0·0932	0·0931	+0·0001
0·25	1·0	15	120	24·28	0·3125	0·0930	0·0931	−0·0001
0·25	1·0	15	120	24·31	0·3130	0·0931	0·0931	±0·0000
0·25	1·0	15	120	24·32	0·3130	0·0932	0·0931	+0·0001
0·25	1·0	15	120	24·34	0·3133	0·0932	0·0931	+0·0001
0·25	1·0	15	120	24·33	0·3132	0·0932	0·0931	+0·0001

These results recorded in A show that stannic chloride is completely hydrolyzed in the presence of the iodide-iodate mixture, and that the iodine liberated on boiling is a measure of the tin present.

The results given in B show that at the temperature of the room complete hydrolysis is also effected by removing from the sphere of action the iodine which at first appears and allowing the mixture to stand two hours before the final titration.

Cobalt.

When cobaltous sulphate is boiled for a considerable time with the iodide-iodate mixture, it is hydrolyzed with the liberation of iodine in amount indicating that the following equation shows the character of the initial reaction.

$$3CoSO_4 + 5KI + KIO_3 + 3H_2O = 3Co(OH)_2 + 3K_2SO_4 + 6I$$

Under the conditions of the experiment potassium iodate is present in excess and exerts an oxidizing influence upon the cobaltous hydroxide, thereby forming black cobaltic hydroxide as follows:

$$6Co(OH)_2 + KIO_3 + 3H_2O = 6Co(OH)_3 + KI$$

After filtering and washing this precipitate and dissolving it with nitric acid, no precipitate was obtained with barium chloride and this solution. This evidence goes to show that the hydrolysis was complete.

The standard of my solution was found by depositing metallic cobalt upon a rotating platinum crucible as the cathode, 3 grms. of ammonium sulphate being used as the electrolyte for 25^{cm^3} of the solution of cobaltous sulphate diluted with 25^{cm^3} of water, using one ampere for current and continuing thirty minutes. The following table shows these results:

TABLE VII.

$CoSO_4$.	$(NH_4)_2SO_4$	Time in minutes.	Co = SO_3 = I.			Mean of entire series.
cm³.	grms.		grm.	grm.	grm.	grm.
25	3	30	0·0528	0·0710	0·2250	
25	3	30	0·0525	0·0706	0·2237	
25	3	30	0·0524	0·0705	0·2234	0·2242
25	3	30	0·0527	0·0709	0·2247	
25	3	30	0·0526	0·0707	0·2240	
25	3	30	0·0527	0·0709	0·2247	

Subjecting portions of cobaltous sulphate to heat with potassium iodide and potassium iodate in the presence of a current of hydrogen to transfer the iodine to a Drexel flask charged with potassium iodide, the following results were obtained:

TABLE VIII.

$CoSO_4$.	KI.	KIO_3.	Time in hours.	Approx. N/10 $Na_2S_2O_3$.	Iodine value calculated.	Iodine value of $CoSO_4$ taken.	Diff.
cm³.	grm.	cm³.		cm³.	grm.	grm.	grm.
25	1·0	15	4	17·80	0·2244	0·2242	+0·0002
25	1·0	15	3½	17·78	0·2242	0·2242	±0·0000
25	1·0	15	3½	17·75	0·2238	0·2242	−0·0004
25	1·0	15	4	17·79	0·2243	0·2242	+0·0001
25	1·0	15	4	17·79	0·2243	0·2242	+0·0001
25	1·0	15	4	17·78	0·2242	0·2242	±0·0000

It should be observed that the iodine value obtained by the action of the iodide-iodate mixture upon the samples of cobaltous sulphate examined is closely comparable with the iodine equivalent of the cobalt found by the electrolytic deposition of the metal, showing that it is an exact measure of the cobalt present in the completely hydrolyzed cobaltous sulphate of ideal composition.

Nickel.

Nickelous sulphate, like cobaltous sulphate, is hydrolyzed completely, after a considerable time, in the presence of the iodide-iodate mixture, likewise yielding iodine, which may be collected similarly and estimated as a measure of the nickel present. Nickelous hydroxide formed in the reaction remains, however, unoxidized by potassium iodate in neutral solution and therefore the following equation will show the final products:

$$3NiSO_4 + 5KI + KIO_3 + 3H_2O = 3Ni(OH)_2 + 3K_2SO_4 + 6I$$

The standard of the solution examined was obtained by the electrolytic process. To 25 cm³ in a beaker of convenient size

an equal volume of water and 3 grms. of ammonium sulphate were added, and a current of one ampere was found sufficient to deposit the nickel upon a rotating platinum crucible in thirty minutes.

Below is shown results of these determinations.

TABLE IX.

$NiSO_4$	$(NH_4)_2SO_4$	Time in	Ni =	SO_3 =	I.	Mean of entire series.
cm^3.	grm.	minutes.	grm.	grm.	grm.	grm.
25	3	30	0·0520	0·0709	0·2246	
25	3	30	0·0523	0·0713	0·2260	
25	3	30	0·0521	0·0711	0·2252	0·2255
25	3	30	0·0523	0·0713	0·2260	
25	3	30	0·0522	0·0712	0·2255	

A portion of 25^{cm^3} of the solution of nickelous sulphate was drawn from a burette into a Voit flask and a solution of 1 gm. of potassium iodide in 15^{cm^3} of the potassium iodate (30 grms. to a liter) was added. This was heated for three hours in the presence of hydrogen to aid in the transfer of the iodine liberated to the receiver—a Drexel flask about half full of water in which 3 grms. of potassium iodide is dissolved. The iodine liberated was estimated with sodium thiosulphate in the presence of starch.

Results of these determinations follow.

TABLE X.

$NiSO_4$.	KI.	KIO_3	Time in	Approx. N/10 $Na_2S_2O_3$.	I. calculated.	Iodine value of Ni. table.	Diff.
cm^3.	grm.	cm^3.	hours.	cm^3.	grm.	grm.	grm.
25	1·0	15	3	17·87	0·2254	0·2255	−0·0001
25	1·0	15	3	17·88	0·2256	0·2255	+0·0001
25	1·0	15	3	17·84	0·2250	0·2255	−0·0005
25	1·0	15	3	17·87	0·2254	0·2255	−0·0001
35	1·0	15	3	17·83	0·2249	0·2255	−0·0006

Thus it appears that nickel sulphate may be completely hydrolyzed in the presence of the iodide-iodate mixture and that the nickel of nickel sulphate of ideal composition can be estimated from the amount of iodine liberated in the action of that salt upon the iodide-iodate mixture.

Zinc.

Zinc sulphate is hydrolyzed in the presence of the iodide-iodate mixture and the reaction might be expected to proceed according to the following equation:

$$3ZnSO_4 + 5KI + KIO_3 = 3Zn(OH)_2 + 3K_2S_4 + 6I$$

For the purpose of experimenting upon this salt, a solution

was made containing 20 grms. to the liter. The standard was found both by determining the zinc precipitated electrolytically and by finding the weight of barium sulphate precipitated by barium chloride.

In the electrolytic process a portion of 25^{cm^3} was in each determination drawn from a burette into a beaker of convenient size; 3 grms. of sodium acetate and 1^{cm^3} of acetic acid were added and with a rotating platinum crucible as the cathode a current of one ampere was passed for 30 minutes, when the deposit was washed with water and alcohol, dried and weighed as metallic zinc.

Results of these experiments are given in the following table:

TABLE I.

Zinc sulphate. cm^3.	Sodium acetic. grms.	Acetic acid. cm^3.	Current. amperes.	Time in minutes.	Zinc grms.	Equivalent of SO_3 grms.
25	3	1·0	1·0	30	0·1153	0·1413
25	3	1·0	1·0	30	0·1146	0·1405
25	3	1·0	1·0	30	0·1149	0·1408
25	3	1·0	1·0	30	0·1147	0·1406

The entire series gives a mean of 0·1408 grm. of SO_3 equivalent to the zinc.

The content of sulphuric anhydride was found by precipitation with barium chloride as barium sulphate, and the results of these experiments are given in the subjoined table:

TABLE II.

Zinc sulphate. cm^3.	$BaCl_2$ cm^3.	$BaSO_4$ found. grm.	Equivalent of SO_3 grm.	Mean of entire series. grm.
25	10	0·4109	0·1408	0·1408
25	10	0·4113	0·1410	
25	10	0·4101	0·1406	
25	10	0·4105	0·1407	

The determinations of zinc and of the barium sulphate gave in the average the same standard for the combined SO_3.

Portions of this solution subjected to heat with a mixture of potassium iodide and potassium iodate liberated iodine, and the amounts of iodine found by titration with sodium thiosulphate are given in the following table:

TABLE III.

Zinc sulphate. cm^3.	KI. grm.	KIO_3. cm^3.	Time in hours.	Approx. N/10 $Na_2S_2O_3$. cm^3.	I. grm.	Equivalent of SO_3. grm.	Mean of entire series. grm.
25	1·0	15	½	27·8	0·3557	0·1123	0·1125
25	1·0	15	½	28·0	0·3582	0·1130	
25	1·0	15	3	27·8	0·3557	0·1123	
25	1·0	15	3	27·8	0·3557	0·1123	

From these results it appears that hydrolysis of the salt ceases before all the SO_3 radical is removed.

In another series of experiments similar portions were boiled in an Erlenmeyer beaker with the iodide-iodate mixture until all the iodine visibly liberated in the reaction was expelled, and the precipitate was then filtered, washed, dissolved in nitric acid and treated with barium chloride. The barium sulphate precipitated, filtered off on asbestos, washed, ignited and weighed was found to correspond almost exactly with the SO_3 radical not removed by hydrolysis in the previous experiments.

TABLE IV.

Zinc sulphate. cm^3.	KI. grm.	KIO_3. cm^3	Time in hours.	$BaCl_2$. cm^3.	$BaSO_4$ found. grm.	Equivalent of SO_3. grm.	Mean of entire series. grm.
25	1·0	15	¾	10	0·0817	0·0280	0·0280
25	1·0	15	¾	10	0·0812	0·0278	
25	1·0	15	3½	10	0·0821	0·0282	
25	1·0	15	3½	10	0·0814	0·0279	

From the results of both Table II and Table III it appears, therefore, that zinc sulphate is not completely hydrolyzed in the presence of the iodide-iodate mixture, and the mean percentage of such hydrolysis is found to be 80·13. So it appears that a one-fifth basic sulphate is formed. The basic sulphate contains 5Zn to $1SO_4$ and is so definite that from the iodine liberated the zinc content may be calculated with accuracy.

The reaction of hydrolysis may be expressed by the equation:

$$15ZnSO_4 + 20KI + 4KIO_3 + 12H_2O = 3Zn_5(OH)_8SO_4 + 12K_2SO_4 + 24I.$$

Of the various metal sulphates mentioned in this paper zinc sulphate is the only one which is not completely hydrolyzed, more or less easily, in presence of the iodide-iodate mixture.

SCIENTIFIC INTELLIGENCE.

I. Geology and Natural History.

1. *The Geodetic Evidence of Isostacy, with a Consideration of the Depth and Completeness of the Isostatic Compensation and of the Bearing of the Evidence upon some of the Greater Problems of Geology;* by John F. Hayford, C.E. Proc. of the Wash. Acad. of Sciences, vol. viii, pp. 25–40, May 18, 1906.—The nature of this short paper is well indicated by its title, and instead of merely stating the more conspicuous conclusions, it may be desirable, in order to indicate its great importance, to give a brief historical review of the place of this subject in geological literature and of the problems upon which it bears, the historical side not being developed in the paper itself.

Since the time of Babbage and Herschel the idea has been entertained by certain geologists, that the greater features of the earth's surface were sustained, not by virtue of the internal rigidity, but in large part rested in equilibrium because of a lessened specific gravity of the crust beneath the more elevated masses; the facts leading to this hypothesis having been pointed out by Petit, who in 1849 discussed the deficiency of gravity beneath the Pyrenees,* and by Archdeacon Pratt of Calcutta, who a few years later called attention to the striking deficiency of mass found to exist by the Indian Trigonometrical Survey beneath the Himalayas and the Plateau of Thibet.†

This conception involves far-reaching consequences in regard to the nature of the earth's interior, implying a superficial heterogeneity of density and a capacity of viscous flowage toward that figure of equilibrium which should tend to bring equal pressures upon all parts of the earth's interior at a certain depth. For this condition of equilibrium Dutton proposed the term of isostacy,‡ now fully incorporated into geological literature. The acceptance of the principle of isostacy, however, immediately raises the questions as to how deep is the zone within which the heterogeneity of density producing the larger and broader surface features is confined? What is the percentage variation in the density of various parts of this zone? What is the departure from true isostatic adjustment exhibited by the surface features? How quickly will response take place to destroyal of the isostatic adjustment through erosion and sedimentation? What is the initial cause of the internal differences in density which lead to the larger features of the earth's surface and which having once originated, isostacy tends to preserve?

It is seen that these questions involve fundamentally the prob-

* Comptes rendus de l'Acad. des Sc., xxix, p. 730.

† Phil. Trans. Roy. Soc., vol. 145, p. 53.

‡ "On Some of the Greater Problems of Physical Geology," Bull. Phil. Soc. of Washington, vol. xi, p. 53, 1889.

lems of continental origin and maintenance, mountain-building and the nature of the earth's interior. On these subjects the long-felt need has been for facts, and it is for these that the present article is especially valuable. Mr. Hayford has utilized the triangulation and astronomic determinations of latitude and longitude within the United States. The preliminary results of the investigation, which is still in progress, indicate that the most probable value of the limiting depth of isostatic compensation is 71 miles and that it is practically certain that the limiting depth is not less than 50 miles nor more than 100 miles. It is certain that for the United States and adjacent regions, including oceans, the isostatic compensation is more than two-thirds complete—perhaps much more.

Internal variations of specific gravity to the extent of three per cent from the mean, both above and below, will account for the ocean basins and plateaus. As a consequence of this limited zone of isostatic compensation it is pointed out that isostatic adjustment involves a subsurface undertow away from areas of sedimentation and toward areas of erosion: this viscous undertow acting as a thrust tending to crumple back the continental margins upon themselves and at least aiding in the formation of mountains. In this connection the reviewer wishes to point out facts not commonly cited, viz.: that Major Dutton perceived as long ago as 1872 the inadequacy of the still popular hypothesis of terrestrial cooling as a sufficient source of mountain-making,* and in 1889 suggested the agency of this lateral undertow.† The efficiency of this agent must depend upon the depth of the compensating zone, its thickness and viscosity. It is doubtful if Mr. Hayford's figures justify elevating this factor to a major place, but the present limitation of the zone makes it at least a minor factor, and Dutton's suggestion in this respect must stand as an example of remarkable scientific prevision. J. B.

2. *Pleistocene Deposits of South Carolina;* by GRIFFITH THOMPSON PUGH: A thesis submitted to the Faculty of Vanderbilt University for the Degree of Doctor of Philosophy, Nashville, Tenn., 1905; 74 pp.—This paper is an attempt at ascertaining what must have been the environmental conditions under which lived the Pleistocene mollusca of the state. To that end the species are tabulated, together with the conditions of environment of their living representatives. The conclusion is reached that at least in South Carolina the Pleistocene sea temperature, if differing at all from that of the present, was slightly higher rather than slightly lower. The method of detailed and tabulated investigation is excellent and should be followed out for other localities. The reviewer would point out, however,

* A Criticism upon the Contractional Hypothesis, by Captain C. E. Dutton, U. S. A., this Journal, vol. viii, p. 113.

† On Some of the Greater Problems of Physical Geology, Phil. Soc. of Washington, vol. xi, pp. 51–64.

that there is nothing to show that the fossiliferous beds concerned were deposited at a time of maximum glaciation, and this possibility must be held in mind in view of the recent tendency to enlarge the estimates of Pleistocene time and to consider it a period of great climatic variability. Such a question has greater force since Collier Cobb has recently made note of finding rounded, subangular and even striated cobbles on the Atlantic side of Currituck Banks off the North Carolina coast, which he regards as having been transported by icebergs from the New England coast during a period of maximum glaciation.* J. B.

3. *The Geography and Geology of Alaska. A summary of existing knowledge*, by ALFRED H. BROOKS, *with a section on climate*, by CLEVELAND ABBE, JR., *and a topographic map and description thereof*, by R. U. GOODE. Professional Paper No. 45, U. S. Geological Survey, 1906; 327 pp., xxxiv pls., 6 figs.—For all except those who have made a specialty of Alaskan geological exploration, this will be the most valuable volume published by the government on the geography and geology of Alaska, giving a general view of the physiographic provinces and of the present knowledge of the country.

It shows what results may be accomplished in the course of a few years by government support for the scientific exploration of a previously unknown land. Apart from the scientific results, it is doubtless true that from an economic standpoint these explorations have increased the value of Alaska to the United States many times the sum of money spent in the explorations. J. B.

4. *Geology and Mineral Resources of part of the Cumberland Gap Coal Field, Kentucky ;* by GEORGE HALL ASHLEY and LEONIDAS CHALMERS GLENN, in coöperation with the *State Geological Department of Kentucky*, C. J. NORWOOD *Curator*. Professional Paper No. 49, U. S. Geological Survey, 1906 ; 239 pp., xl pls., 13 figs.—This well written and illustrated report contains 40 pages on the general geography, physiography and geology of the region, followed by 170 pages on the geography and stratigraphy of the coals. The volume contains much of scientific interest and is of great economic value. J. B.

5. *The Pleistocene Deposits of Sankoty head, Nantucket, and their Fossils ;* by J. A. CUSHMAN. Pub. Nantucket Maria Mitchell Assoc., I, 1906, 21 pp., 3 pls.—This paper brings together all that is known regarding the Sankoty Head section, the occurrence of the fossils, horizons, a list of the fauna (86 species, of which 66 are Mollusca), and another of the literature of these deposits. This paper should be studied in connection with an article recently published on the same deposits, in the Journal of Geology, December, 1905, pp. 713–734, by J. Howard Wilson, where about 15 additional species are listed. C. S.

* Notes on the Geology of Currituck Banks, Journal of the Mitchell Society, vol. xxii, No. 1, pp. 17–19.

6. *The Tertiary and Quaternary Pectens of California;* by RALPH ARNOLD. Prof. Paper 47, U. S. Geol. Surv., 1906, pp. 264, 53 pls.—This extensive monograph on the Cenozoic Pectens of California also gives a very valuable "brief outline of the different Tertiary and Pleistocene formations of California" and "their typical fauna as far as known" (pp. 9–40). In order to give a clear definition of the various Pectens and their geologic range, it was necessary to examine "all of the available marine Tertiary paleontologic material from the west coast." The total thickness of these deposits aggregates 21,000 feet. The classification of the Pectens is practically that of Dr. Dall in "Tertiary Fauna of Florida."

The genus *Pecten* and its subgenera *Patinopecten*, *Nodipecten*, *Chlamys*, *Lyropecten*, *Æquipecten*, *Plagioctenium*, *Pseudamusium*, *Amusium*, *Propeamusium*, and *Hinnites* are defined on pages 45–50. Of species and varieties there are 93, and of these 50 are new. These are distributed as follows: Eocene 4 (restricted), Oligocene 5 (all pass upward), Miocene 38 (28 restricted, 4 pass upward), Pliocene 37 (10 pass upward), Pleistocene 20 (17 in recent faunas), Recent 25 (16 also fossil).

The illustrations look natural, being nearly all retouched photographs without attempting to show more than the specimens reveal. It will therefore be easy for subsequent workers to identify these species as defined by Dr. Arnold. The work is thoroughly up to date and is indispensable to all students of the Mollusca. C. S.

7. *Cambrian Faunas of China;* by CHARLES D. WALCOTT. Proc. U. S. Nat. Mus., 1906, pp. 563–595.—This is the third paper on the Cambrian material collected by Mr. Blackwelder in China. The final report on the fossils by Dr. Walcott, and on the geology by Dr. Willis, will be published next winter by the Carnegie Institution of Washington.

This paper describes 34 new species and one new genus *Blackwelderia*. The remarkable abundance of Trilobites in the Cambrian is again noticeable in this paper, where 27 species are described. C. S.

8. *Plant Response as a Means of Physiological Investigation;* by JAGADIS CHUNDER BOSE, M.A., D.Sc. Professor, Presidency College, Calcutta. London, New York, and Bombay, 1906. (Longmans, Green & Co.)—In a previous notice of this interesting and suggestive treatise, the promise was given that in a subsequent issue of this Journal a short analysis would be made of the principal chapters. The work is divided into nine parts, which are not of equal rank, some of them being merely convenient headings for minor but generally allied subjects. Thus, for instance, two parts are devoted to the Ascent of Sap and Growth, respectively; topics which are special under larger questions.

Part First considers Simple Response. In this the plant is regarded as a machine responding to external stimuli and giving distinct pulse-records. The sensitiveness of plants is practically

universal; according to the author, wherever there is a living tissue, no matter how sluggish it may seem, response may be elicited by appropriate means. There are certain conditions which are conspicuously favorable to the exhibition of mechanical response, and these conditions have been carefully studied. Such study has convinced the author that there is no difference, except in degree, between the ordinary and the so-called sensitive plants. The mechanical response in ordinary leaves and the longitudinal response of radial organs have been examined in detail by means of newly-devised apparatus, which appears to possess the power of recording even the slightest possible movement after stimulation of the plant or its parts. The responsive curvature of molecularly anisotropic organs receives a good deal of attention, and the complex phenomena are resolved into their simpler terms or factors. Lastly, under this heading, comes the consideration of the relation between stimulus and response, and also, the effect of the superposition of stimuli. Here tetanus in plants is described.

In Part 2d the author treats of the modification of response under various conditions. Here are studied the theories concerning different types of response, the effects of anæsthetics, poisons, and other chemical agents on longitudinal response. The effects of temperature receive attention in a special chapter, as does also the "death-spasm" in plants. The critical point of death is determined by inversion of the thermo-mechanical curve. In connection with this topic the author examines at considerable length the subject of local fatigue and regional death.

Excitability and conductivity are considered in Part 3. Polar effects, electrotonus, electrotactile and electromotive methods, and the latent as well as the "refractory" periods are fully treated of. Then follows the consideration, in part 4, of multiple and autonomous response; and the similarities of rythm in animals and plants are clearly stated. The ascent of sap and the general subject of growth are next presented, and the supposed relations of both to certain stimuli are insisted upon. Following come Geotropism, Chemotropism, and Galvanotropism. Near the close of the last chapter in this part the author considers the effect on growth of "electrification" of the soil. To the subject of Heliotropism the author devotes the whole of part 8. He takes up even the effect of invisible radiation and the action of the high frequency Tesla current. Torsional response receives a fair share of attention. Besides this is considered the topic of pulsatory response and the swimming movements.

Part 9 concludes the treatise with general reviews and a final examination of the continuity of physiological response in plant and animal. Three features render this work of great interest: (1) the summaries at the close of the chapters, (2) the descriptions of entirely new types of delicate apparatus, and (3) the fact that the greater part of the experiments were conducted under the most favorable conditions in a tropical climate upon tropical

plants. The treatise is stimulating and suggestive throughout. Even where one cannot agree with the conclusions of the author he must confess deep indebtedness for new lines of thought.

G. L. G.

9. *Heather in Townsend, Mass.*—In this Journal, Oct., 1888, I gave a full description of the occurrence of *Calluna vulgaris* at a locality not far from the railroad station in West Townsend, near the New Hampshire line. On Saturday, July 14, 1906, this place was revisited by me for the purpose of ascertaining what changes might have occurred in the distribution of the plants. In a subsequent notice I shall hope to give details regarding the present condition of the heather, but at present I will merely state that the plant has steadily extended over a larger area, and, although in certain spots it has suffered from various agencies, it appears to be so well established as to wage a strong and perhaps successful fight with the contending native plants. The best time to visit this interesting station is early August. At that date, the whole area is said to be a mass of bloom. At this present writing, however, there were only slight indications that the flowers this year would be numerous, but the dried capsules from last year's blossoms were very plentiful. G. L. G.

10. *The Biology of the Frog;* by Samuel J. Holmes, Ph.D. Pp. ix+370, with 94 figures. New York, 1906 (The Macmillan Company).—This work is designed particularly as a text-book for students in the college or university who have had some training in elementary biology. A study of this text accompanied by suitable practical work in the laboratory will lead naturally to the study of comparative morphology and physiology. This work is in the broadest sense a natural history of the frog, whose systematic position, relationships, habits, food, enemies, parasites, breeding periods, hibernation, powers of regeneration, movements, and so on are described. Then follow chapters on the external characters, internal structures, development, and general histology. Each of the principal organ systems of the body is then taken up in detail with an account of the functions of each part accompanying the description of the structure. The two concluding chapters deal with instincts and tropisms, and include a brief discussion of the frog's intelligence. The figures and diagrams, which are carefully chosen and well printed, are mainly from standard works, although a few are original. Such a detailed knowledge of the biology of a single animal will meet the needs of the college student who is preparing for the study of medicine, and will form a convenient reference book for teachers of biology in secondary schools. W. R. C.

11. *A Course in Vertebrate Zoology. A Guide to the Dissection and Comparative Study of Vertebrate Animals;* by Henry Sherring Pratt. Pp. x+299. New York and Boston, 1906 (Ginn & Company).—The plan of the book follows closely the lines adopted by the author in his Invertebrate Zoology, which was published several years ago and has proven a convenient

laboratory guide. As in the earlier work, the type system is followed, a single representative of each of the more important groups of vertebrates being taken up. It contains not merely directions for the work in the laboratory but also short descriptions of parts difficult to study, with brief statements as to function and morphological significance. Each dissection is quite independent of the others, so that the animals can be studied in any sequence. Like its predecessor, this book is sure to form a valuable addition to the already numerous laboratory guides.

W. R. C.

12. *The Life of Animals. The Mammals;* by ERNEST INGERSOLL. Pp. xi + 555, with numerous illustrations, including 15 colored plates. New York, 1906 (The Macmillan Company).—A popular work, written in an entertaining style, containing a storehouse of facts about the familiar as well as the less generally known animals. These facts of general interest are brought together from widely scattered scientific treatises, books of travel, and reports of hunters. Each of the groups of mammals from the highest to the lowest is taken up in turn with illustrations, descriptions, and anecdotes of some of the representatives. Many of the illustrations are from original photographs and drawings and greatly enhance the value of the work. W. R. C.

II. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *Recent Text-books on Astronomy. — A Compendium of Spherical Astronomy,* with its Applications to the Determination and Reduction of Positions of the Fixed Stars; by SIMON NEWCOMB. Pp. viii, 444. New York and London: 1906 (The Macmillan Company).

An Introduction to Astronomy; by FOREST RAY MOULTON. Pp. xviii, 557, with 24 tables and 50 figures. New York: The Macmillan Company. London: Macmillan & Company Ltd., 1906.

Laboratory Astronomy; by ROBERT WHEELER WILSON. Pp. ii, 189, with 89 figures and 7 tables. Boston, New York, Chicago, London: 1905 (Ginn & Company).

The works here noticed meet the needs of students of Astronomy from the Nautical Almanac Office to the High School, except for the computation of orbits and perturbations.

The volume by Newcomb is the most important work in practical Astronomy that has appeared in the present generation and is well worthy of the reputation of its author. Aside from its intrinsic merit, it is the more valuable as "the first of a projected series having the double purpose of developing the elements of practical and theoretical Astronomy for the special student of the subject, and of serving as a hand-book of convenient reference for the working Astronomer in applying methods and formulae."

If Professor Newcomb completes the series it will be a worthy monument both to himself and to American Astronomy and will leave little for other writers to do until the accumulation of new material calls for a new harvest, in the same way that the present work is made necessary by the advance of knowledge since the writings of Bessel, Chauvunt and Oppolzer.

The most urgent want which the present volume supplies is that of improved methods for deriving and reducing the positions and proper motions of the fixed stars made necessary by the period of 150 years through which these positions now have to be reduced. In this and all parts the book is full of new and most valuable material, of which may be mentioned the appendix of 26 tables, most of which can be found in no other text-book, and a chapter on observatories and star catalogues.

Moulton's Introduction to Astronomy has the same justification as Newcomb's volume. It is intended for the student of descriptive Astronomy as a part of general culture, and gives access to the stores of information which have accumulated since Young's unequaled text-books were published, accumulations which frequent revisions of Young's series have not been wholly adequate to keep pace with.

The amount of new material is made evident at a glance by the new cuts which meet the eye wherever the book is opened, such as Chandler's diagram of the variations of the pole, Todd's chart of paths of total eclipses up to 1973, Maunder's figure of the dimensions and distribution of sun spots for 25 years, a spectroheliograph of the sun by Hale, etc.

Both in plan and arrangement the book differs considerably from the conventional form, the design being to use something of the laboratory method throughout, connecting theory as closely as possible with practice and familiarizing the student with the lines of thought and chains of reasoning by which the great theories of the noblest of the sciences have been developed.

It is too much to expect the felicity of statement, the perfection of clearness and conciseness which is found in Young's writings. By comparison the writer seems somewhat prolix and lacking in perspicuity.

Wilson's Laboratory Astronomy is an excellent book to use with the preceding in a course where time permits. It presents a large number of valuable practical exercises for the average student, carefully worked out and requiring such apparatus, largely of the author's own devising, as can be provided in quantities at small cost, so that a large class can be set to work together on the same exercise (e. g. mapping the sun's diurnal motion), under the supervision of an instructor in an ordinary recitation room and from data collected by themselves. W. B.

2. *The Publications of the Royal Society of London.*—A circular recently issued by the Royal Society calls attention to the present method of publishing the Proceedings in two series, viz., A, containing mathematical and physical papers, and B,

those of biological character. Volumes 76–77 of each series have now appeared, of about 600 pages royal octavo, with illustrations. "A main object of this new arrangement was to render the Proceedings more accessible to workers by placing the two groups of subjects on sale separately, at a stated price attached to each separate part of a volume when it first appears. Moreover, with a view to promoting the circulation of the complete series, it has been directed that a subscription paid in advance to the Publishers at the reduced price of 15 shillings per volume for either series, shall entitle subscribers to receive the parts as soon as published, or else the volumes when completed, in boards or in paper covers, as they may prefer." Each number of Proceedings also contains an announcement on the cover of the more recent memoirs of the Philosophical Transactions as published separately in wrappers and the prices at which they can be obtained. It is hoped that this arrangement may facilitate the prompt circulation of the journals of the Society.

3. *Physical Optics;* by Robert W. Wood, Professor of Experimental Physics in the Johns Hopkins University. Pp. vi, 546, with 325 figures. New York and London, 1905 (The Macmillan Co.).—Prof. Wood's book is a remarkably interesting compendium of our present knowledge of Physical Optics. It is very complete and up to date on the experimental side, and while some of the mathematical portion is abbreviated, many results are derived which are found in few if any other books on light. For example, it is proven that, for regular reflection, a surface must be smooth to within an eighth wave length (p. 36), also that Fermat's Law requires that the time be a minimum or a maximum (pp. 55, 61), that the phase is uniform within a quarter wave length over a surface of diameter equal to the wave length divided by the apparent diameter of the source $=\cdot 05^{mm}$ for sun light (p. 123); further, Rayleigh's proof is given that the magnification equals the compression of the wave front (p. 65). The reader is surprised to find no reference to Wood's successful diffraction color photographs. Considerable attention is appropriately devoted to the author's work on sodium vapor in the region of the D-lines; a vapor with a refractive index as high as 1·38 and a dispersion which separates a double line with components twenty times as close as the sodium lines by an amount as great as the distance between the red and the blue of the spectrum formed by a 60° glass prism (p. 346), which shows enormous rotation in a magnetic field (p. 426), which gives a series of fluorescent spectra, corresponding lines in which will appear upon stimulation with proper monochromatic light (p. 408) and which exhibits optical resonance (p. 486) and lateral radiation of the stimulating light (p. 451). There is little to criticise. Misprints are few and not such as to confuse the reader. Does not the graphical explanation of the absence of a back wave (p. 8) assume what is to be proven? The reviewer was unable to find a clear derivation of the condition for resolution. As an American book upon Mathematical

Optics, it is much to be desired that we may have before long Prof. Gibbs' Lectures upon the Electro-Magnetic Theory of Light.

ARTHUR W. EWELL.

Obituary.

Professor Henry A. Ward, the veteran mineralogist, scientific traveler and collector, was struck by an automobile in the streets of Buffalo on July 4 and died almost immediately after. Notwithstanding his seventy-two years of age, he was still in full health and vigor. He was born at Rochester on March 9, 1834, studied at Williams College, at Cambridge with Agassiz, and later for four years at the School of Mines in Paris. For six years from 1859 he taught Natural Science at the University of Rochester. The greater part of his time and energy he devoted to travel, with collecting in mineralogy, geology and natural history as the main object and incentive. Throughout his life his interest and enthusiasm for this work never flagged; trips to Europe, Asia, Australia, Africa and South America were repeated at short intervals. Many institutions have obtained their collections through his efforts and the large amount of material he accumulated has been the basis of the Natural Science Establishment which bears his name.

During the later years of his life his interest was particularly aroused by the study and collection of meteorites, the very difficulty of the undertaking serving to stimulate him. One large collection passed from his hands to the Field Columbian Museum in Chicago, and another to Mr. C. S. Bement. His efforts culminated, however, in the Ward-Coonley collection now on deposit and exhibition at the American Museum of Natural History in New York City. Beginning with a small nucleus in 1894, within ten years it had taken the first place among the great collections of the world. This was a unique work calling for all his energy, perseverance and tact, together with liberal expenditure. Could the history of the collection in detail be written it would be full of the interest of travel and adventure; as a typical case may be mentioned his trip to Persia and interview with the Shah, leading to his obtaining a large mass of the remarkable Veramin meteorite.* Up to the day of his death his interest in meteorites and his energy in obtaining new specimens were unabated. He had also accumulated a large amount of material relating to the history and scientific investigation of meteorites, from which he proposed to prepare an exhaustive volume on the subject.

Baron C. R. von der Osten Sacken, the eminent Russian entomologist, died in May last at the age of seventy-eight years.

Dr. Ludwig Brackebusch, Professor of Geology at Hannover, died recently at the age of fifty-seven years.

* A brief account is given in this Journal, v. xii, p. 453.

CRYSTALLOGRAPHY.

Our new Catalogue XIX, with many illustrations, has just come out (post free on application). Of its contents, the following may be mentioned:

1. *New Collection of 416 Crystal-models of wood*, containing all the crystal forms and combinations represented by illustrations in the 4th ed. of P. Groth's "Physikalische Krystallographie, - - - - - - - - 550 Marks.
2. *Large Collection of 928 Crystal-models of wood* to illustrate the crystal-forms of the minerals; arranged by Prof. Dr. Hintze, - - - - - - - - - - - 1800 "
3. *The Brush-Penfield Collection of 225 Crystal-models of wood* for illustrating Chapter V of the Brush-Penfield "Determinative Mineralogy, etc.," - - - - - 230 "
4. *New Collection of 450 Crystal-models of paste-board*, systematically arranged by Professor Dr. K. Vrba, - 950 "
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6. *Stands for crystal-models* in various forms and constructions.

LANTERN SLIDES

For Lectures on Petrology and Geology.

The new edition of *H. Rosenbusch text-book* (by H. Rosenbusch and E. A. Wülfing), Vol. I, "Mikroskopische Physiographie der Mineralien," has just come out in two parts, each of which contains a considerable number of photographic reproductions showing the microscopical features and structures of the rock-forming minerals. By the kindness of the author and publisher we have been able to prepare *lantern slides of the original photos*, which we now offer in two sets of 72 slides each; collection A, representing the figures on the plates IV–XV of part I; collection B, those of the plates I–XII of part II.

Collection A: Growth of crystals, inclusions, aggregates, deformations, etc., 72 slides, - - - - - - 100 Marks.
Collection B: The rock-forming minerals, 72 slides, - - 100 "

We also remind the reader of the following collections of lantern slides:

I. *Petrological*, arranged by Professor Dr. K. Busz, in Münster, i. W.

1. 50 slides; mode of occurrence of the rock-forming minerals, - - 70 Marks.
1a. 20 slides; do. crossed nicols, - - - - - - - - 28 "
2. 80 slides; microstructure of the rock-forming minerals, - - 112 "
3. 36 slides; the structures of rocks, - - - - - - - 50 "
4. 100 slides; systematic collection (according to Rosenbusch) of typical rocks, - - - - - - - - - - 140 "
4a. 75 slides; do. crossed nicols, - - - - - - - - 105 "

II. *Geological*, arranged by Professor Dr. van Calker, in Groningen.

1. 30 slides; Historical Geology, type-fossils, - - - - - 42 Marks.
2. 50 slides; Tectonic Geology, - - - - - - - - 70 "
3. 60 slides; Volcanism, - - - - - - - - - 84 "

III. *Paleontological*, arranged by Professor Dr. van Calker, in Groningen.

1. 30 slides; Paleontological problematics and pseudo-fossils, - - 42 Marks.
2. 25 slides; Protozoa (Foraminifera, Radiolaria, etc.), - - - 35 "
3. 20 slides; Spongiae, - - - - - - - - - 28 "
4. 22 slides; Brachiopoda, - - - - - - - - - 31 "
5. 40 slides; Lamellibranchiata, - - - - - - - - 56 "
6. 50 slides; Pisces, - - - - - - - - - 70 "
7. 12 slides; Amphibia, - - - - - - - - - 17 "
8. 50 slides; Sauropsida (Reptilia and Aves), - - - - - 70 "
9. 70 slides; Mammalia, - - - - - - - - - 100 "

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(See this Journal, xvi, 264, September, 1903.)

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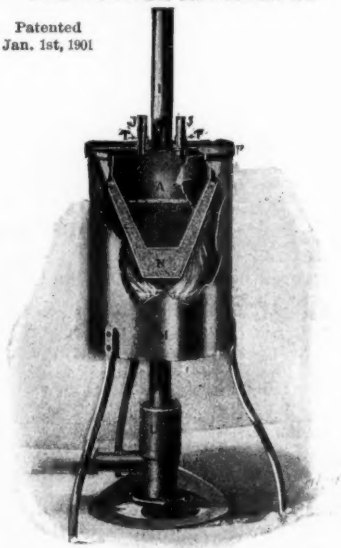

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